1990

Aspen symposium '89: proceedings. Duluth, Minnesota, July 25-27, 1989

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CONTENTS

PLENARY SESSION

CONCURRENT SESSION I - ASPEN ECOLOGY AND SILVICS (Continued)

CONCURRENT SESSION II - ASPEN MANAGEMENT AND SILVICULTURE

CONCURRENT SESSION III - ASPEN PRODUCTS AND UTILIZATION

POSTER SESSION

PREFACE

In 1972 a symposium was held in Duluth to review knowledge of the aspen resource based on research and practices of the 1950s and 1960s. The objectives of this 1989 symposium were to provide a forum for the exchange of knowledge concerning aspen derived in the intervening years and to provide a compilation of this knowledge in the form of these proceedings. Most papers presented at Aspen Symposium '89 are included in this document. They are assembled as they were presented even though some may fit more appropriately in another session. A number of papers based on poster presentations are also included. In reviewing this information it can be seen that while many things have remained the same, there are contrasts between 1972 and 1989.

Aspen demand in Minnesota and the Lake States has grown significantly. This increased demand has been predominantly due to the composite panel industry (waferboard and oriented strandboard), a virtually unknown industry in 1972. Management techniques including aspen harvesting for the production of timber and wildlife habitat presented in 1972 were implemented, resulting in significant improvements to the current aspen forests. Innovative management practices being researched in 1972, such as hybrid aspen and aspen thinning are still being researched but are approaching the point of implementation. Concern expressed in 1972 that use of the resource was necessary for the sustained future of the aspen forest, which would otherwise age and progress through succession to other species, is still a concern today. Additional research has advanced information in new forecasting models, nutrient cycling, and new products. What was considered a weed species before 1972 is now described as "Champion Species" or "Queen of the North" by some authors.

For seventeen years the 1972 Aspen Symposium Proceedings (USDA Forest Service, General Technical Report NC-1) has been widely used as a reference tool. It is hoped that this publication will serve as a reference tool for the next few years. However, knowledge and technologies change rapidly and it would be seemly not to wait another seventeen years before a third symposium is held to exchange knowledge about the aspen resource.

As the first symposium was published by the North Central Forest Experiment Station (NCFES), it seemed appropriate that this proceedings also be published by NCFES. This they graciously agreed to do. Other sponsors are also acknowledged for their contributions to Aspen Symposium '89. In particular the 1987 appropriation from the Minnesota Legislature, which funded the Aspen Resource Study at the Natural Resources Research Institute and which prompted this symposium, was pivotal.

The symposium and this document would not have been possible without the contributions of many people, the organizing committee, the moderators, the numerous authors, the reviewers of papers, etc. Specific acknowledgment of the efforts of Bill Berguson, Chris Edwardson, John Gephart, John Pastor, Don Perala and John Tevik is made. Thanks go to Jane Gephart for the cover design. Special appreciation is given to Julie Johnson and Tami Lawlor without whose assistance the symposium could not have been held nor these proceedings produced.

INTRODUCTION TO SYMPOSIUM AND THE ASPEN RESOURCE STUDY

Roy D. Adams and John S. Gephart[1]

ABSTRACT.--As a lead in to this 1989 symposium a review of the 1972 symposium is given. It is interesting to note that many of the challenges of today were also the challenges of yesterday. In 1989 demand for aspen by Minnesota's forest industry has almost doubled in the last ten years. A study of the aspen resource was undertaken at the request of the Minnesota Legislature. Three major activities were performed; information collection, data analysis and information dissemination. A general discussion of preliminary findings and conclusions is given. This symposium is one important aspect of the information dissemination role.

While preparing for this symposium we located slides and a summary of the 1972 symposium prepared by the University of Minnesota College of Forestry, the USFS North Central Forest Experiment Station and the Minnesota Forest Industries Information Committee. We felt that it would set the stage well for Aspen Symposium '89. The following synopsis is based on this summary. It is significant to remember that the previous symposium was held seventeen years ago and while some things change others stay very much the same. One major difference between this symposium and the 1972 one is the emphasis on products and utilization. It was a minor part in 1972 whereas this time it has equal weight along with ecology and silvics, and management and silviculture. In addition to this review a summary of the status of the 1989 aspen resource study carried out by the Natural Resources Research Institute (NRRI), University of Minnesota, Duluth is given.

SYNOPSIS OF 1972 SYMPOSIUM

The story of aspen is an unusual tale because these trees have been such a vigorous and inseparable part of the northern hemisphere. Aspen lineage reaches from "Jacobs well" in the book of Genesis toward an ever brighter future. It is a "rags to riches" story; from weed to valuable resource; from newsprint, tissue and plywood to choice food for wildlife. This summary focuses on aspen in the Lake States and adjacent parts of Canada.

ASPEN RANGE

Quaking aspen is found across Canada, north to the Bering Sea coasts of Alaska, and southerly down the Rocky Mountain chain to central Mexico. In the eastern third of the United States, bigtooth aspen follows the Appalachian Mountains south to Kentucky and North Carolina, and west to Iowa and Minnesota. Quaking aspen grows on a wide variety of soils, from shallow, rocky soils to loamy sands and onto heavy clays. Some of the best stands occur in the northern Lake States, Manitoba and Saskatchewan on grey, glacial drift, rich in lime. Bigtooth aspen is generally found on the well drained

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sandier uplands, but reaches its greatest size along floodplain streambanks and is not nearly as flexible in site requirements as quaking aspen. Quaking aspen is a major component of six forest types and minor component of 27 types and is an aggressive colonizer. In contrast, bigtooth is a major component of only the aspen type. Both are shortlived, very intolerant, and express dominance well. Bigtooth will reach a larger size and live longer than quaking aspen on better sites.

ASPEN ECOLOGY

Aspen flowers are separate and borne on different plants. In the Lake States, aspens usually flower in April and leaf in May. Wide clonal variations in suckering capacity, growth rates and disease susceptibility, show the natural stands of aspen to be genetically and ecologically very diverse. Aspens require maximum sunlight for best growth. Root suckers are the most common means of regeneration and through rapid growth tend to maintain their dominance. Repeated vegetative reproduction of aspen results in the formation of clonal stands, each may contain from a few to several hundred trees and may be spread over 3 to 4 acres of land. A fully stocked stand of aspen when clearcut or burned may produce 40,000 suckers per acre, but mortality is high and by 30 years of age these numbers are reduced to 1000-2000 stems and at age 40 stocking averages 300-400 trees per acre.

In overmature aspen stands selective cutting of superior clones can genetically weaken the parent stock. Because aspen does not reproduce adequately under a partially cut canopy, the roots of these better clones decay in 3 to 4 years, and when the remaining poorer trees are removed, these are the ones that reproduce the stand. Clearcutting is essential to maintain the better clones and to keep a broad genetic base. In both the United States and Canada large areas of aspen forests will not be harvested, and natural succession will change the composition of these stands. Where aspen is found on the cooler, wetter sites, especially in the northern Lake States and Canada, succession will be towards balsam fir or white spruce. On the moist, fertile soils, succession will be towards climax hardwoods, such as sugar maple, basswood, ironwood and red maple. Where aspen is mixed with paper birch and red or jack pine, the pine and birch can be expected to outlive it. But they too will be replaced, probably by a shrubwood type, with a distinct shrub canopy and scattered remnants of these successional species.

Recent research in northern Wisconsin has shown that soil texture and water holding capacity are critical factors in maintaining aspen. As the percentage of silt and clay increases, the average site index increases. Soil nutrient levels have little effect on aspen growth, while available moisture is of major importance to aspen growth. A water table within the rooting zone will increase aspen growth. Water tables deeper than 8 feet have little effect on growth. Water tables less than 2 feet from the surface will decrease growth.

The environmental factors that control growth also influence the rate of change in species composition. On coarse-textured soils, conversion to other species is seldom a problem while aspen stands on medium-textured soils show a moderate conversion rate and stands on fine-textured soils can rapidly convert to climax species. After one rotation, aspen will not be a major species on these soils, unless special efforts are made to retain it. The best aspen sites may be lost to the northern hardwood types unless management practices such as shearing and prescribed burning are increased. Loss of the good aspen sites would decrease average growth and volume per acre.

ASSOCIATED WILDLIFE

The possibility of conversion can be of great significance to other members of the aspen ecosystem. One has but to look at the distribution of aspens and ruffed grouse to see the close relationship between the two. Aspens are important to ruffed grouse in several ways. The male flower buds are rich in protein and fats and are usually available regardless of snow conditions. These buds are clustered on rigid stems that facilitate rapid feeding. Aspen leaves provide a significant amount of grouse diet in the summer. Of equal importance to the grouse is the age and density of the aspen stands. Immediately after cutting or fire, high-density sucker growth provides the best summer-long habitat for grouse broods. At 8-12 years, as aspen stands thin to below 8000 stems per acre, they become preferred for breeding habitat. Still later, at age 25 (density of less than 2000 stems per acre), the pole stands provide nesting cover for hens and deep-snow roosting for winter survival. These stands begin to provide the flower buds essential to carry the grouse over winter. To maintain good ruffed grouse populations, various age classes of aspen must be available within the birds foraging range.

Porcupines, beaver, snowshoe hares, squirrels, owls, and lynx are all found in the aspen woods, but one cannot discuss aspen in the Lake States without talking about white-tailed deer. Aspen is a major deer-producing forest type and not enough aspen is being cut and regenerated. As a result, in 1972 deer herds in the Lake States were declining. Surveys from 1961 to 1965 in Michigan showed a direct correlation between the average buck kill and the acreage of aspen. Aspen forests, especially those under 30 years of age, are the major deer producers. Removal of the overstory is needed to maintain and renew deer range. Cutting or shearing specifically for deer in the three Lake States has averaged only 10,000 acres per year for the past 3 years. When the additional acreage of aspen occurring in other types is also considered, it becomes obvious that the habitat renovation program to date has been inadequate. To reverse this trend, Michigan launched a deer habitat management plan in the primary deer producing townships.

INSECTS AND DISEASES

Insects are the most numerous plant eaters in the forests and play a major role in determining the extent and vigor of aspen forests. Aspens are hosts to a wide variety of insects. The forest tent caterpillar influences the aspen forest through defoliation, sometimes over as many as 100,000 square miles. Widespread tree mortality has not occurred, but growth reduction may amount to two cords per acre. Another major defoliator is the large aspen tortrix, which in past infestations has affected 10,000 square miles. Again little mortality of aspen has been recorded; the principal effect is growth reduction. The most serious wood borer in aspen is the poplar borer. Two-thirds of all mature quaking aspen may be attacked. Tunnels made by the larva cause wind breakage and degrade and serve as infection courts for fungi. The best practice is to maintain well stocked stands and clearcut them at maturity. The aspen root girdler makes a spiral gallery that girdles the sucker and can severely damage new stands. Over 300 insects are recorded on aspen, and the role they play in the life of a stand is not well understood.

Although stains in aspen are plentiful and cause processing problems, decay causes the greatest volume loss in the aspen type. The bulk of this damage is attributed to Fomes igniarius. One of the common leaf diseases found on aspen is caused by Venturia tremulae also known as "shepherds crook" or "top dieback." This disease is common in young stands. Cankers are the most common disease on aspen, and in many areas Hypoxylon canker is regarded as the most serious. Poorly stocked stands show more infection than well stocked stands, and the infection is usually greater along the edges of the stand. Hypoxylon is not nearly as serious on bigtooth as on quaking aspen. In 1972 the 200 million cubic feet of volume estimated lost each year in the Lake States was approximately equivalent to the net annual growth for the type and the desirable harvest level. So, annual growth and utilization could be doubled if Hypoxylon were eliminated. On the non-timber side, Hypoxylon infections cause small openings that may contain browse species and thus favor deer herds. It may result in some aspen stands being less attractive, but infections are scattered in small patches and probably do not affect the aesthetics.

In the future we may find that the leaf and root diseases cause more damage than is now assumed. This could be true, especially if short rotations are implemented. But perhaps the greatest long term impact from aspen diseases will be on distribution of the type itself. As older stands die and open up, the result will be type conversion, unless we increase the rate of harvest, reduce the impact of diseases and insects, and regenerate these stands to aspen. The primary requirement in regenerating aspen stands is to clear the harvested areas as soon as possible. Unmerchantable trees, such as those left after a commercial clearcut, should be eliminated by felling or other means immediately following cutting.

There are several new developments in breeding and establishing promising aspen hybrids. By cutting flowering branches from aspen in winter and forcing them indoors, catkins can be induced to shed seed. Establishing these improved aspen in plantations depends largely on reducing sod competition. Herbicides have not worked well but mechanical cultivation two or three times a year for two years after planting can produce 8-foot saplings. Some of the hybrid crosses are showing great potential. A cross of Populus tremuloides (diploid) with P. tremula (tetraploid) growing near Eagle River, Wisconsin, averages 41 feet in height and 5 inches in diameter at 11 years.

RESOURCE AVAILABILITY

Taking a broader look at the resource, we see that Canada has five times as much aspen as the United States. But this is not the whole story. The net merchantable volume of aspen in Canada is widely dispersed from Ontario to British Columbia. In contrast to this, the great bulk of the aspen volume in the United State is concentrated in the Lake States, with a lesser amount in Colorado. Canada, is using only 5 percent of the allowable annual cut and estimates of future aspen use in Canada show no great changes in this trend. Even after the turn of the century, less than half of Canada's allowable annual cut will be utilized. In the Lake States in 1920, 3000 cords or 4 percent of the total cut was aspen. By 1970 this had risen to nearly 2 million cords, or close to 50 percent of all the pulpwood cut. In the Lake States about 3/4 of the aspen volume is in the aspen type; about 1/10 in the northern hardwood type and the balance evenly distributed throughout other types.

The current apparent surplus of aspen will not continue indefinitely if historical trends of growth, utilization, and breakup continue. The Minnesota units have the brightest outlook. Aspen harvesting in the northern Wisconsin-Upper Peninsula of Michigan units after increasing for 15-20 years, will then likely diminish. Forest industries drawing aspen from Wisconsin and Michigan may then have to shift their areas of procurement within those States or not increase their use of aspen. Positive management practices must be initiated soon to markedly affect future aspen supplies.

INTENSIVE MANAGEMENT

One of the innovations is the growing of native and improved aspen on short rotations. Measurements and harvesting information on sucker stands indicate that short rotations of 10-20 years and chipping the complete tree in the woods can more than double production at harvest time while reducing waste and transportation costs. Fertilization and irrigation of native and genetically improved aspen give promise of additional major increases in cellulose production.

While most management guides do not recommend thinnings or intermediate cuts in aspen, except on the very best sites, aspen has responded well to thinnings. Eleven years after this 7 year old stand was thinned, the stems average 4.8 inches in diameter at breast height (DBH). In contrast, the stems in an unthinned part of the stand average only 3 inches DBH. Production of sawlogs or veneer will be increased where thinnings are made early in the rotation. Recent studies have shown that given current costs and prices and considering timber values alone, it is more profitable not to thin. Unless the price of aspen increases significantly or the value of other amenities increases, extensive management is likely to remain the rule in the aspen forests.

MECHANIZED HARVESTING

One important factor that may help to change the entire aspen picture is the development of mechanized harvesting in the Lake States over the past 10 years. These new systems have the potential to greatly improve the utilization of aspen, insure adequate regeneration, and provide more and better wildlife habitat with little adverse impact on the soils. Mature aspen stands lend themselves well to mechanized harvest. The trees are relatively even sized, there is a high volume per acre, and such sites permit year-round harvesting. Uniform size allows full utilization of all stems, thus insuring a clean clearcut and dense sucker regeneration--in most cases better and more vigorous than that of the original stand. Increasing use is being made of the tree-length system in which trees are felled and limbed at the stump, and then transported with high-speed rubber tired skidders. The trend towards equipping mill yards to accept and handle tree-length wood will promote further expansion of this system. The full-tree system has been used to a limited extent in harvesting aspen. A comparison shows that the fully mechanized operations result in a more complete clearcut and eliminate more of the residual trees than does the conventional shortwood system. This is extremely important in influencing the character and stocking of the next forest stand.

UTILIZATION

Aspen is used by 85 percent of the operating pulp mills in the Lake States using a number of processes. The light colored aspen pulp insures high printing quality and opacity, and has sufficient strength to hold together well on the paper machines or printing presses. The obvious importance of aspen as raw material for the pulp and paper industry should not overshadow its many other uses. Uniformity of structure makes it highly desirable for use in chip or flake products. The availability of small hydraulic loaders makes it more practical to sort out those "bolts" that can be put to better uses than chips or pulp. These clear bolts are well suited for peeling into aspen veneer and plywood, which is finding a ready market in both structural and interior uses. Highly automated operations permit the use of smaller diameter trees for both chips and lumber. Conventional and newer types of sawing equipment produce lumber for cut stock, window sash, crating, pallet parts, and studs for the building trades. Many of the clear grades of aspen lumber are destined for use in fine furniture to provide warmth, beauty and utility in everyday living.

SUMMARY

If ever there was a tree that could boast of being the "true champion" of multiple use, it is the versatile aspen. In addition to serving a wide variety of man's needs, it provides home and food for wildlife, heals our scarred landscapes, and provides a brilliant splash of fall color to dazzle the eyes. Aspen must have been the tree the writer of the Book of Job had in mind when he penned:

> Yet there is hope for a tree, if it be cut down, that it will sprout again and its shoots will not cease!

1989 ASPEN RESOURCE STUDY

Demand for aspen (Populus tremuloides) by Minnesota's forest industry has almost doubled in the last ten years. According to Minnesota DNR demand is expected to rise from 1.8 million cords in 1989 to 2.7 million cords in 1996. This further expansion will be possible, resulting in the creation of hundreds of new jobs, provided that industry can be assured of long term aspen supply. There are concerns about this supply and this study was undertaken by NRRI at the request of the Minnesota State Legislature.

The scope of the study was broad. The general intent was to determine the future availability of aspen fiber to existing and proposed industries in Minnesota and to assess the impacts of public policy, resource characteristics and forest management on future resource availability. Three major project activities were carried out: information collection, information assessment, and information dissemination. Input had been sought from public and private land managers along with wood procurement personnel to determine areas of greatest concern. These issues were being assessed through the development and use of a geographically specific wood procurement model. A general discussion of the preliminary findings and conclusions is given.

Several limitations to determining the future resource supply were encountered in this effort. These were:

1. The most recent inventory data for Minnesota was published in 1977 and collected between 1973 and 1977. The age of this data limited projections to only 20 years into the future.

2. The uncertainties associated in anticipating the future, i.e., predicting fuel costs, management practices and industry demand, etc..

3. The analytical techniques available for forecasting supply and demand.

In light of these limitations the answer to the question of the sustainability of future timber supply depends not only on what kind of future one anticipates but how one measures and characterizes supply. Results of this study, as well as the efforts of other University and public agencies, and the industry will help provide a clearer picture of the opportunities and challenges to ensure an adequate supply of aspen to maintain and expand the wood fiber industries in the state.

INFORMATION GATHERING

Input was obtained through many meetings with members of the forestry community in order to identify major issue areas. The meetings were conducted to provide direction to the study. In addition, technical information was gathered through literature searches and analyses of existing inventory data bases. The literature search resulted in the development of a microcomputer-based aspen literature database which includes over 1750 citations for North America. This reference collection is being used by NRRI staff and can be made available to others interested.

INFORMATION ASSESSMENT

Resource assessments of this magnitude are complicated by variations in the geographical distribution of land ownership, the resource, demand and location of mills, and differences in products manufactured. Discussions of how to approach this analysis led to the development of an integrated geographically-specific resource model on a PC-based system. This model combines inventory data, transportation data, a forest growth model, a harvest scheduling model, and graphical display output. Each of these components are modules and can be modified to allow the changing of assumptions and incorporation of new data as it becomes available.

Inventory plot data for Minnesota and Northwest Wisconsin was obtained from the U.S. Forest Service (USFS) North Central Forest Experiment Station. One major goal of this work was to develop tools which would be suitable when new inventory data become available for Minnesota.

A transportation network was developed from existing 1:2,000,000 scale United States Geological Survey (USGS) data. The USFS inventory plot data was overlaid on the transportation network to calculate distances and transportation costs between locations. Other USGS data (1:100,000 scale) was used to determine the distance of each plot from the highway system to evaluate forest road building costs.

The U.S. Forest Service "STEMS" forest growth model was used for forest growth projections on inventory plots. In order to use this model it was modified for PC use.

The harvest scheduling program, which selects plots for harvesting based on mill demand was developed by NRRI. Characteristics of the inventory plots such as land ownership, species composition, species characteristics, harvest costs, and transport costs are considered in making the decision when a plot is harvested.

Computer programs displaying results of the analysis have been developed. These include animated programs to depict growing and changing forests, programs showing transportation distance and cost contours for specific mill locations and graphics depicting plot information geographically.

INFORMATION DISSEMINATION

Information dissemination has occurred through three activities. The first has been through a series of presentations held by NRRI and at conferences such as the Timber Supply Conference held in Grand Rapids, Minnesota in September 1988, the second will be through this Aspen Symposium and the resultant proceedings, and the third will be a publication of the final report.

In 1972 a symposium was held in Duluth to review knowledge of the aspen resource based on work performed in the 1950s and 1960s. Since that time additional research and practice has advanced information in a number of areas. These include new forecasting models, nutrient cycling, hybrid poplar and aspen, and new products. There have been natural changes in the resource and renewed emphasis on the supply of aspen fiber. This 1989 symposium was held in response to these developments.

RESULTS AND DISCUSSION

With the current high demand for aspen wood fiber, forest industry and land managers must have new inventory information and the time periods between inventories must be shortened. Concerns which have been expressed about the supply of aspen during the time period of 2000 to 2010 appear to be justified. Currently the Minnesota aspen resource is heavily skewed to older age classes. This is the result of aspen establishment resulting from the pine harvesting, agricultural land abandonments, and fires in the early part the century and the low utilization of aspen prior to the mid 1970s, leaving few acreages less than 40 years old. Today some of the aspen resource is beginning to succeed to climax forests species such as spruce/fir and northern hardwoods.

During the next twenty years the aspen resource will undergo significant successional changes. This will result in increased species diversity of stands being harvested, and an increased average age of stands harvested, which will provide a decreased volume of aspen per acre, and a decrease in the quality of aspen harvested due to heart rot (Fomes igniarius).

The large acreage of mature aspen stands now available for harvest have allowed loggers and mills to select the most economical stands. These stands have generally been located near the mills, close to the all season highway system, and have been the lowest costs stands to harvest. During the next 20 years, harvested stands will be located farther from mill sites and have a higher transportation cost, and be located further from all season roads and require increased forest road building programs. Loggers will also have higher harvest costs due to reduced volumes per acre and poorer quality, and have increased stumpage prices reflecting increased competition by mills as their procurement zones expand and the number of economical stands available for harvest decrease.

Increasing costs and decreasing quality can be partially offset through the accumulative impacts of a number of different efforts.

VALUE ADDED PRODUCTS

A targeted effort to increase the value of the products manufactured by the wood composite and lumber industries is required. This will decrease the percentage of the raw material cost to gross sales. Not only can this assist in the continuation of these industries and their associated employment, the additional manufacturing opportunities at these companies may result in increased employment and economic impact to the states economy.

SPECIES SUBSTITUTION

Other species are available for harvesting and substitution of these in various products will increase the utilization of other species in the state. This will directly and indirectly reduce the aspen demand. Approximately 18 percent of the aspen resource is found in other forest types, increased utilization of these stands would further decrease the pressure on the aspen resource by liberating aspen that would otherwise be unavailable for harvesting.

INTENSIFIED FOREST MANAGEMENT

Several potential activities which are at various stages of research and development could assist the supply situation in the relatively near future. Hybrid aspen and hybrid poplar plantations are genetically superior aspen that grow to merchantable size in 15 to 20 years instead of the 40 to 50 years in natural aspen stands. Each of these methods has advantages and disadvantages but the acceleration of work in these areas could have positive impacts. Another technique, thinning of aspen stands, is targeted towards natural stands and encourages natural stands to reach merchantable size at an earlier age, potentially 30 years. These efforts are intended to address the supply during the next twenty-five years.

PRIVATE FOREST MANAGEMENT

In the future there will be an increased emphasis on timber supply from the non-industrial private landowners. Both private and public programs which encourage good management will enhance timber supply. These programs include direct technical assistance and tax incentives.

CONTINUED EMPHASIS ON EXISTING PROGRAMS

Funding for the management of the state and county lands in Minnesota has increased considerably during the last ten years through funding from the state, counties and federal government. This increased funding has been partially responsible for the recent growth in the wood products industry by improving the level of forest management, thus assuring long term timber supply upon which the industry expanded. Continued funding for road access and management is needed to continue the work already started.

CONCLUSIONS

Minnesota's aspen resource is undergoing significant changes. These changes are due to a dramatic increase in demand during the previous decade and from successional changes that are occurring in the forest. There is no single solution to the challenge of providing sustainable wood fiber supply. Instead the solution will be the accumulative impact from a large number of activities and efforts by all groups concerned. In conclusion, a number of activities should be continued or emphasized. These are:

1. Timely completion of forest inventories.

2. Forest access through road construction and maintenance.

3. Intensified land management (thinning, hybrid aspen and poplar plantations).

4. Development of processes and products which will assist in the substitution of aspen by other species, such as birch.

5. Development of higher value products for companies manufacturing commodity products such as oriented strandboard.

6. Evaluation of legislative initiatives which directly and indirectly impact resource management and supply.

ASPEN ECOLOGY AND MANAGEMENT IN THE WESTERN UNITED STATES

Norbert V. DeByle[1]

ABSTRACT.--Quaking aspen occurs on more than seven million acres of the interior western United States. It is seral on most sites, usually giving way to more shade-tolerant conifers. Regeneration is almost exclusively by root suckering -- seedlings are a rarity. Discrete clones that occupy several acres are the rule on mountainous western landscapes. Management practices reflect the values of this ecosystem. These values, in decreasing order of importance, are: livestock forage, wildlife habitat, watershed cover, esthetics and recreation, and wood products. Wood products are gaining in importance, thus encouraging more active management of this important type.

This paper emphasizes those aspects of the ecology and management of quaking aspen (Populus tremuloides Michaux) that are unique to the montane interior West of the United States and adjacent Canada. Much of the information in this paper comes from DeByle and Winokur (1985) -- which is an extensive, 283-page, literature review and state-of-the-art document. The reader is referred to it for citations of the original sources of publications and ideas prior to 1985. Citations made in that review do not appear in this paper.

ECOLOGY

Quaking aspen has a greater range than any other tree species on the continent. In the interior West it is confined to relatively moist sites (16 to 40+ inches annual precipitation) that have cold winters and a reasonably long growing season. These conditions restrict aspen to low elevations and often south slopes in the northern portions of its range. It grows at progressively higher elevations southward along the Rocky Mountains. At the southern end of its range in Mexico it is virtually restricted to mountain tops. Most commercial sawtimber concentrations are confined to elevations between 7,000 and 10,000 feet in the Rocky Mountains of Colorado, northern New Mexico, and southern Utah. Despite the spotty distribution (Fig. 1), two Rocky Mountain states -- Colorado and Utah -- are among those with more than one million acres of aspen (Table 1).

Regeneration by seed is a rarity, despite large quantities of viable seed being produced almost every year. Asexual regeneration by root suckering has produced clones that commonly are much larger than those found in the Lake States or elsewhere in the East. Clone sizes of 2 to 5 acres are common; clones up to 100 acres in size have been found. Most small groves of aspen on the western landscape are individual clones, they often have a domed shape, with younger suckers on the periphery. Even where stands are extensive, the clones are discrete and, because of large morphological variation among them, obvious to most observers.

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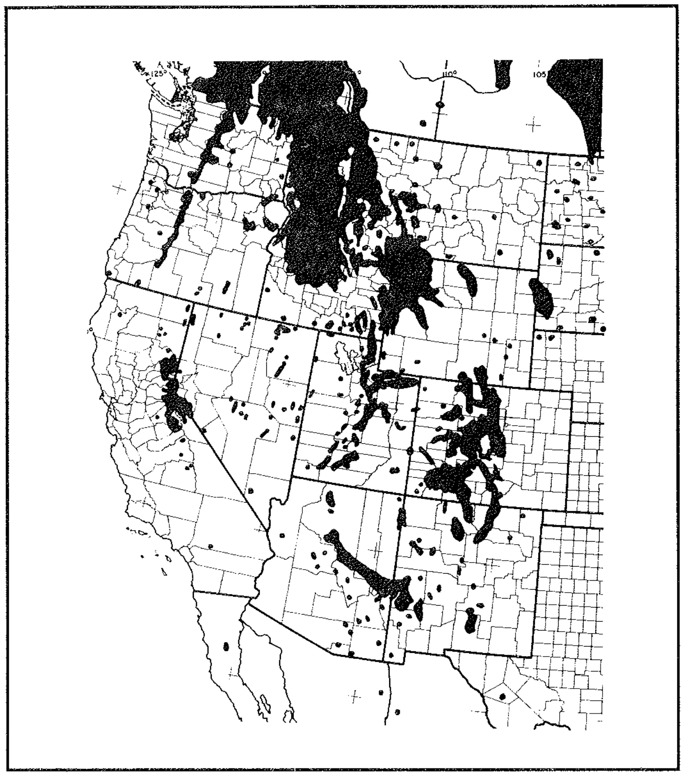

Figure 1.--The range of aspen in the conterminous western United States (Little 1971).

Table 1.--Area (in thousands of acres) of aspen forests in the interior West.[1]

	Commercial	Noncommercial[2]	Total
Idaho	99	305	404
Montana	46	209	255
South Dakota	21	2	23
Wyoming	210	257	467
Utah	717	931	1,648
Colorado	2,854	628	3,482
Nevada	6	221	227
New Mexico	338	98	436
Arizona	112	13	125
TOTAL	4,403	2,664	7,067

[1]Acreage from Green and Van Hooser (1983).

[2]Noncommercial acreage includes land that is reserved from cutting and that which is incapable of producing more than 20 cubic feet of wood per acre per year.

The morphology of individual trees in the Lake States and the West is similar, except that the bark on western aspen remains smooth throughout the tree's life. Rough, fissured bark is found only on the lowest couple feet of the bole, even on the largest trees. Sometimes gnawing by rodents will produce corky, roughened bark up to the snowline (3 to 5-feet); and sometimes gnawing by wintering elk (Cervus elaphus) produce rough patches about 5 to 7 feet above the ground.

Aspen is a shade intolerant species that commonly occurs in even-aged stands, especially on sites where competition with more shade-tolerant tree species is intense, as in the Lake States. Most western aspen stands are even-aged and single storied, with all stems originating over a 2- to 4-year period. Some are two-storied, with veterans in an overstory that survived stand decline (from a light fire, high mortality from disease or insects, or commonly from a period of overgrazing). These two-storied stands usually have an understory of essentially even-aged suckers that originated when conditions were favorable, such as after heavy grazing ceased. Despite its intolerance, aspen in the West often occurs as climax stands that are nearly all-aged. They regenerate as the overmature stand breaks up and increased radiation reaches the forest floor. Climax aspen stands do not occur on sites with significant conifer invasion.

In the West, most aspen trees live longer and grow more slowly than those in the Lake States. Tree ages in excess of 100 years are common. However, on most sites, we can expect stand breakup at 120-140 years. Early sucker growth is slower than in the Lake States, taking 2 to 5 years to reach breast height. On montane sites with deep snowpacks, these young suckers are commonly flattened and sometimes damaged by settlement or creeping of the snowpack. Later growth on good sites will reach 80 feet or more at 80 years.

ASSOCIATED VEGETATION

Aspen can be found growing in association with a wide variety of vegetation. Not only is it distributed over a broad latitudinal range, but it also grows along moist stream bottoms, on dry ridges and south slopes, on both shallow and deep soils, and on soils derived from a variety of parent materials. It grows in all mountain vegetational zones from the alpine to the basal plain. Both the tree species with which aspen is associated and the understory composition vary widely over this broad amplitude. For example, in a sample of over 2,000 aspen communities in four physiographic provinces (Central Rocky Mountains, Basin and Range, Colorado Plateau, and Southern Rocky Mountains), only one species, mountain snowberry (Symphoricarpos oreophilus), occurred in at least half the communities in all four provinces (Mueggler 1985).

Most aspen communities are multilayered. Sufficient light penetrates this deciduous tree canopy to support a lush understory. This is in marked contrast with the paucity of herbs and shrubs in nearby stands of conifers. In some communities, a tall shrub stratum occurs beneath the aspen trees, forming an intermittent layer from 6 to 12 feet high. Chokecherry (Prunus virginiana) and serviceberry (Amelanchier alnifolia) are most common. Low shrubs and tall forbs frequently form a continuous stratum about 3 to 4 feet tall. Snowberry and rose (Rosa spp.) are the most common shrubs, and species of Agastache, Aster, Senecio, and Rudbeckia are the most common tall forbs. A stratum of low forbs (usually species of Thalictrum, Galium, Osmorhiza, and Valeriana) and/or grasses (species of Agropyron, Bromus, Elymus, and Poa) and sedges (Carex spp.) is always present (Mueggler 1985). In the western U.S., annual production of this undergrowth commonly exceeds 1,000 pounds per acre. Production of a ton per acre on very good sites during years of copious precipitation is not uncommon.

In much of the West, aspen is the only deciduous tree on upland sites. Commonly it is a seral tree in coniferous forests, associated most often with subalpine fir (Abies lasiocarpa), but also with Engelmann spruce (Picea engelmannii), white fir (Abies concolor), blue spruce (Picea pungens), Douglas-fir (Pseudotsuga menziesii), lodgepole pine (Pinus contorta), ponderosa pine (P. ponderosa), and sometimes at higher elevations with limber pine (P. flexilis) (Mueggler 1985). After a stand replacement fire or similar perturbation, aspen may dominate a site for 50 to 200 years; but, if a seed source is present, many of the associated conifer species will slowly replace the aspen in the overstory tree canopy.

In recent years, most of the western aspen ecosystem has been classified into either habitat or into community types. These classifications have helped put order into the chaos facing managers of this widespread and diverse forest type (Mueggler 1985, 1988).

INSECTS AND DISEASES

Aspen is prone to attack by many diseases. Only a few, particularly the cankers, are likely to kill the adult tree. But many weaken the tree and make it susceptible to death from some other cause. Several fungi attack the foliage. The most common is black leaf spot, caused by Marssonina populi, which often causes widespread defoliation of mature aspen after wet weather early in the growing season. Ink spot, caused by Ciborinia, is a similar foliage disease that is common in the West.

Decay of aspen boles is important to management for wood products. It becomes important at about 80 years and controls the upper limits of rotation ages at about 120 years. About a dozen fungi species will decay living trees; the most important of which is Phellinus tremulae. Other fungi decay the butts and roots of aspen and make it subject to windthrow.

Aspen is very susceptible to infection by several cankers. Among these, sooty-bark canker, caused by Cenangium singulare, is the most lethal in the West. It will kill the bark and girdle the stem in a few years. Black or target canker, caused by Ceratocystis fimbriata, is perhaps most frequently encountered. The important canker of the Lake States, hypoxylon canker, caused by Hypoxylon mammatum, has caused only minor impact in the West.

Aspen is host to at least 33 insect species, but only a few will kill otherwise healthy trees. Others, however, provide portals for disease entry. The defoliating insects are most conspicuous. Among these, the western tent caterpillar (Malacosoma californicum) periodically defoliates aspen over extensive areas. Outbreaks of the large aspen tortrix (Choristoneura conflictana) and the aspen leaftier (Sciaphila duplex) sometimes occur. Potentially the most destructive insects are those that bore into the bark and wood. Among several important borers, the poplar borer (Saperda calcarata) is very common and may directly cause mortality.

WILDLIFE AND LIVESTOCK

The aspen forests in the West provide important habitat for many species of wildlife. In the coniferous forests, aspen groves may be the only source of abundant forage; in the grasslands they may be the sole source of cover. A primary value of the western aspen ecosystem during the past century has been production of forage for both wildlife and domestic livestock. There are at least 135 species of birds and 56 species of mammals that inhabit the aspen type. This diversity and species richness reflects the variation in this ecosystem over a wide geographic area, as well as the variety of understory types, elevational zones, and associated tree species within the aspen type locally.

Some birds, such as the sandhill crane (Grus canadensis), are part of the ecosystem locally; others, such as the western wood-pewee (Contopus sordidulus), are a part of almost the entire western aspen ecosystem. Among the game birds, there are six species of ducks, two species of forest grouse, two of pigeons, the sharp-tailed grouse (Tympanuchus phasianellus), and the wild turkey (Meleagris gallopavo) that inhabit aspen forests. Perhaps only one-half to two-thirds of the bird species found in aspen and mixed aspen-conifer forests actually breed in this habitat.

The many mammal species found in the western aspen ecosystem range in size from the dwarf shrew (Sorex nanus) to the bison (Bison). Several species appear to prefer the aspen type and are important as game, for aesthetics, or have an obvious impact on the plant community. These species include: moose (Alces), elk (Cervus elaphus), deer (Odocoileus spp.), snowshoe hare (Lepus americanus), cottontail rabbit (Sylvilagus nuttallii), beaver (Castor canadensis), porcupine (Erethizon dorsatum), and pocket gophers (Thomomys talpoides).

The many species of wildlife, particularly the mammals, and domestic livestock (sheep and cattle) have major impacts on the aspen ecosystem. Grazing by cattle and sheep of the undergrowth has been the primary consumptive use of the aspen forest type in the West. In addition, wild ungulates graze the abundant and succulent forage under aspen, often selecting this forage source over several others available in the vicinity. Excessive use by ungulates, both wild and domestic, can have adverse effects on both the understory plant community and aspen regeneration. Trampling by ungulates also impacts these strata of the aspen community and sometimes has adverse effects on aspen regeneration. Pocket gophers, though subterranean, also are grazers. They are ubiquitous in western aspen forests, and in some stands are abundant enough to consume as much as a quarter of the below-ground plant productivity. Mineral soil constantly is being brought to the surface of the forest floor by pocket gopher activity.

Browsing has a direct impact on aspen trees. Domestic sheep, deer, elk, and moose all will readily browse aspen. In too many instances, one or more of these species has been responsible for decimating young stands of aspen suckers or of preventing sucker development under a degenerating overmature stand of aspen trees. In addition to browsing, elk on their winter range have a predilection for chewing the bark off aspen trees. Barking provides entry for pathogens and sometimes girdles even mature trees. Voles, hares, and porcupines also bark aspen, but cause little impact on the montane aspen communities of the western U.S. During population eruptions, snowshoe hare damage to aspen regeneration in the boreal forest of Canada and Alaska can be significant.

FIRE

Fire plays an important role in the aspen ecosystem. Most aspen forests in the West are seral and have been dependent upon fire for their perpetuation. If not burned, they would have been replaced by conifers, or, on drier sites, by shrubs and grasses. Among the fire types, aspen is somewhat of an anomaly because it is difficult to burn. However, this thin-barked species is readily killed by fire and the root system responds with copious, rapidly growing, root suckers. Even a mere scattering of aspen in the coniferous stand commonly will restock the area with a new aspen forest after severe fire. The even-aged stands of aspen now prevalent throughout the West owe their origin to fire.

The lack of fire control, and perhaps the use of fire by aboriginal man, contributed to a much greater fire frequency in the past than exists today. In recent decades, the few fires that occurred in the aspen type contributed little to aspen regeneration. We calculated a fire return interval at present of 12,000 years (DeByle et al. 1987). In much of this century, the lack of fire as a stand-replacement mechanism no doubt has been the cause for most of the aspen stands in the West being in the mature to over-mature age classes. In the Intermountain Region, 78% of the stands inventoried were 80 years or older (Mueggler 1989).

It appears that a moderate intensity fire that kills most or all the overstory will stimulate adequate suckering (Brown and DeByle 1987). Herbage production also increases for several years following fire (Brown and DeByle 1989). Both grasses and forbs increase after low to moderate fire severity, forbs increase most after high severity fires. Aspen sucker production comes from deeper roots after fires of high severity, increasing from an average depth of 2 or 3 inches to about 4 inches (Brown and DeByle 1987).

If fire occurs at infrequent intervals (e.g., 50-150 years) and is intense enough to kill most of the aspen and competing conifers, then most aspen sites in the West will retain viable stands of aspen. More frequent fires may adversely effect site quality for aspen. Complete fire protection will allow conifers to take over the majority of sites. Without human intervention, fire appears to be necessary for the continued well-being of aspen on most sites where aspen is seral.

RESOURCES AND VALUES

In contrast with most other vegetation types, the aspen forest type in the montane West possesses several resource values, none of which dominates and controls its management.

The undergrowth in aspen stands produces nearly as much forage as adjacent meadows. This complex mix of grasses, forbs, and shrubs has furnished excellent range for cattle and sheep in the West for more than a century. Livestock grazing continues to be the leading use on many acres.

The aspen ecosystem also provides habitat for a myriad of wildlife species, several of which are important game animals. Among these, the wild ungulates also forage upon the aspen undergrowth, and in some instances, compete with domestic livestock. The juxtaposition of aspen stands with open meadows, conifer forests, brushfields, and riparian zones on the western landscape provides an especially rich complex of wildlife habitats. The value of aspen to wildlife is recognized as perhaps equal to its importance as livestock range on increasingly large acreages.

Aspen provides excellent cover on the mid- to high-elevation watersheds in the mountains. This deciduous ecosystem protects the soil and prevents erosion on steep mountain slopes. It consumes less water than conifer forests on similar sites, largely because it is defoliated during half the year. Annually, in the Rocky Mountains, about 12 inches of water is yielded to streamflow from typical aspen forests that receive 24 to 30 inches precipitation. The importance of this water is increasing as human populations grow and make greater demands on a limited and largely fixed supply of this essential resource.

Aspen in the West is rapidly increasing in value as a wood resource. There is approximately 4.2 billion cubic feet of growing stock available on the 4.4 million acres of commercial aspen land. Only a couple decades ago, aspen was considered a weed tree except for a few specialty products, such as excelsior. As recently as 1975 only 0.1% of the net volume was cut annually. Today it is being harvested for dimension stock, matchsticks, excelsior, particleboard and flakeboard, firewood, paneling, and other uses. It is still much underutilized, but markets are developing. However, much of the aspen in the mountains is on relatively remote and inaccessible sites, where its value as wood probably never will justify road construction to permit its harvest. Also, the aspen in the interior West is too far from paper mills to permit its economical harvest as pulpwood -- a principal use in the Lake States.

Whether or not aspen trees are directly utilized, they have value silviculturally as a nurse crop for shade-tolerant species that do not become established in full sunlight, such as Engelmann spruce, white fir and subalpine fir. These species can grow well under aspen, but later may require aspen removal for optimum growth. In a sense, aspen also serves as a nurse crop for its forage-rich undergrowth. On many sites, without the shade of overstory aspen, many of the shade-tolerant undergrowth species, particularly forbs, would die.

Aspen stands on the mountainous western landscape, especially when growing in a mosaic of meadows, conifer stands, and barren, rocky mountain peaks, have great aesthetic appeal. This value is especially great in the autumn when the aspen clones are in full color -- ranging from pale yellow to orange. This amenity is becoming increasingly important as our population grows and expands its outdoor recreational pursuits. Quaking aspen also has increased greatly in popularity as a landscape plant in urban and suburban areas in the Rocky Mountain states.

MANAGEMENT

The aspen ecosystem may be managed for one or more of the assets already discussed. It is truly a multiple-use type, but with a limited market for its fiber. Most forest types are managed for their economic value as timber. This value is the source of money for management activities. In contrast, the principal uses of the aspen ecosystem have seldom generated enough money to actively manage the overstory portion. In the past, adequate measures have not been taken to ensure that this seral species is retained where other resources benefit from its presence. This, coupled with an effective fire control program, has placed many aspen forests in jeopardy of soon being replaced by conifers through natural succession. Management intervention is needed to retain these seral aspen stands, to maximize wood fiber yields, to provide an optimal variety of wildlife habitats, to retain the rich forage resource under seral aspen, and to provide maximum yields of high-quality water. Fortunately, wildland managers in the West recognize this problem and today are increasing their efforts to effectively treat and manage the aspen in their jurisdictions.

In some instances, the manager may wish to convert some sites now in aspen to other vegetation (e.g., conifers for greater monetary return, grassland for greater water yields and a different forage mix, etc.). In others, the aspen on the site may need to be modified to optimize its value and uses (e.g., all-aged stands of aspen may be regenerated as an array of even-aged stands to maximize production of wood fiber). But, in most instances today, the manager will be taking steps to retain seral or deteriorating aspen in the forest complex.

Two conditions determine the management direction needed to maintain aspen stands: (1) the status of aspen-to-conifer succession, and (2) the status of aspen regeneration in a deteriorating stand. If the stand is rapidly being taken over by conifers, the conifers must be reduced through clearcutting, burning, or at least through selective removal. This removes the competing trees and, in most instances, will stimulate additional aspen suckering. If conifers are not invading, then conditions need to be provided to encourage enough sucker initiation and growth to replace the aging trees. Mueggler (1989) provided a general decision model to determine the type of action needed to maintain aspen stands (Fig. 2). Spraying in that model refers to top-killing the aspen overstory with herbicides. (It can be as effective as fire or clearcutting for stimulating copious aspen sucker development.) "Adequate" sucker reproduction depends upon the uses and values of the stand being managed. Wood fiber production and some wildlife habitats would require uniform and full or nearly full stocking, perhaps beginning with a sucker stand of 8-10,000 per acre; whereas sufficient aspen to shade the undergrowth or to provide an aesthetically pleasing setting could, to the timber manager, be very grossly understocked with only, say, 500 or 1000 suckers per acre.

Aspen-to-conifer succession may progress rapidly over several decades, or it may progress insidiously over hundreds of years. Action to maintain aspen on the site must be taken before major mortality of the aspen overstory occurs due to overtopping by invading conifers. This action might be selective cutting to remove the conifers, clearcutting both conifers and aspen, a stand replacement prescribed fire, or some other means of setting back succession and stimulating aspen regeneration.

Pure aspen stands that are beginning to break up should have sufficient advance regeneration to replace the overstory. If sucker reproduction is inadequate, small, and obviously not developing into saplings as openings occur, then management action is required. If browsing by livestock or big game is responsible for the lack of reproduction, then protection from this impact for several years should permit adequate sucker-to- sapling development. If it is due to a problem inherent to the clone(s) on that site, then more drastic means of altering the hormonal balance to trigger sucker development is in order. Clearcutting, prescribed fire, or herbicide spraying to top-kill the aspen overstory may be used (Mueggler 1989).

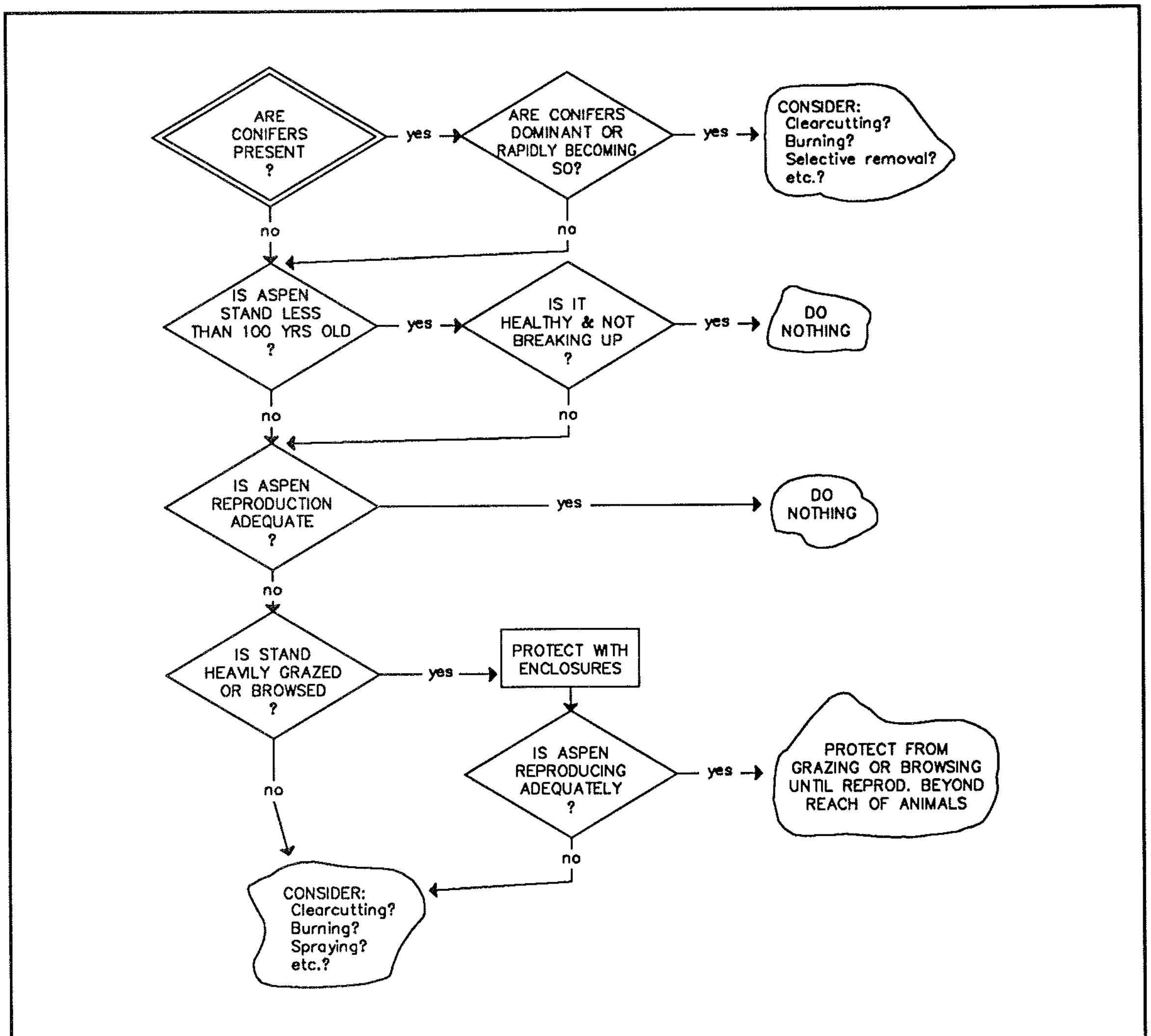

Figure 2.--Decision model for maintaining aspen stands in the West (from Mueggler 1989).

Partial cutting can successfully regenerate some aspen clones, whereas others need a major disturbance to trigger suckering. Partial cutting should not be used in commercial quality stands. The residual stems are too frequently damaged by logging and will become diseased. Those that survive cannot be harvested later without damaging the new stand, they must be left to become overmature and die.

Prescribed fire can be used to regenerate aspen in stands with a great enough fuel load to produce fire-line intensities that kill 90% or more of the trees. This is accomplished with flame heights of at least 2 feet, which produce char heights of a foot or more on aspen stems (Brown and DeByle 1987). Unfortunately, effective prescribed fires are limited to stands with an understory of shrubs or with a fairly heavy cover of cured herbaceous vegetation (Brown and Simmerman 1986).

Livestock grazing or heavy use by big game can destroy aspen regeneration, even when a dense stand of suckers comes up after clearcutting or fire. This is especially true on small clearcuts or burns that attract ungulates to the heavy crop of palatable forage. Careful grazing management, especially of sheep, is necessary for at least 3 to 5 years after suckers arise so they will outgrow the reach of browsing livestock. In critical areas we have recommended fencing; but in most, rest rotation grazing, good herders, and proper placement of salt blocks and water will satisfactorily control animal use.

Concentrations of big game, especially elk, can be very destructive to aspen regeneration. Most damage is done to aspen on winter and spring range. Again, fencing can be used, but this is prohibitively expensive. Herd size control by hunting is the most satisfactory answer if aspen is to be retained on heavily used ranges.

Rotations of aspen for sawlog production in the West should fall between 80 years (when decay and deterioration of overstory trees begins) and 140 years (when mean annual increment culminates in the better quality stands). A tentative rotation of 110 years is suggested for stands with site indexes greater than 75 feet (at 80 years), and 120 years for those with site indexes between 60 and 75 feet. A precommercial thinning at about 20 years will put greater growth on the remaining stand. Thinning of aspen, a species that is self thinning as the stand develops, is an economically questionable practice today. Thinning also has an adverse effect on habitat for some wildlife species.

The aspen ecosystem can be managed for several resources simultaneously. But, on any given site, aspen usually has been managed primarily for a single resource. High quality clones on good sites are best suited for sawtimber, those on medium sites for other wood products, and poor clones and clones on poor sites for wildlife or forage production. Aesthetics may be emphasized in key recreation areas. Management for water yield may be the primary consideration on important watersheds.

Even when management focuses on one resource, the others may be affected and must be considered. For example, abundant forage will be produced even under the most intensive management for timber, aspen ranges will yield good quality water under all but the most abusive livestock or game management practices, and the aspen-conifer-meadow mix in the montane setting will retain its scenic qualities under intensive management for any other single resource.

Most techniques for managing other forest types, especially hardwoods, for scenic and recreational values can be applied to the aspen type. Aspen fits well into management for dispersed recreational activities; but, it does not tolerate concentrated use, such as that found in established campgrounds. Carving on trees, vandalism, destruction and removal of young suckers, and trampling of the soil will eventually destroy the aspen in these areas of concentrated use. Aspen can best be used as a scenic resource for recreation purposes in summer and autumn. It also is a preferred forest type on and near ski areas and cross- country ski trails.

Aspen ecosystem management to maximize both forage production and water yields is quite compatible. Both are greater without conifers in the stand. Aspen clearcuts yield more water and produce more forage than do the nearby aspen forest. These facts point to short rotations of, say, 40 or 50 years in areas where water and forage are the prime values.

Aspen ecosystem management for wildlife becomes quite complex. The myriad of species require a broad array of habitats. Management for selected game species continues to be emphasized, but there is a growing tendency to manage for species and habitat diversity. Perhaps providing a balance of aspen age and size classes in small even-aged units on the landscape best fits the above objectives. The mixed aspen-conifer forest appears to provide the greatest variety of niches, and thus the greatest species diversity. Hence, in contrast with management for maximum forage and water yields, the mixed forest should be retained for best wildlife habitat. Overmature aspen trees, especially after decay begins, provide excellent homes for cavity nesting birds. In any management scheme, aspen snags can be retained without damage to other resources.

In summary, I again refer you to our 1985 book, "Aspen: Ecology and Management in the Western United States" (DeByle and Winokur 1985), as the source for most of the information in this paper. In this book we have 32 pages of listed literature citations as well as many observations and management suggestions by the 21 contributing authors. This paper is only a short synopsis of that volume as well an update of some aspects, such as fire management, in which recent research has made significant contributions.

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NUTRIENT CYCLING IN ASPEN ECOSYSTEMS

John Pastor[1]

ABSTRACT.-- The cycles of nutrients in aspen ecosystems from the Great Lakes region to Alaska have been intensively studied by researchers since the early 1970s. These studies have revealed several patterns common to most aspen stands. In general, aspen rapidly takes up large quantities of nutrients and stores them in woody tissues, particularly bole bark and bole wood. The small amounts of nutrients that are returned in leaf litter are released relatively rapidly during decay. The net result is that aspen retains nutrients effectively within the ecosystem, leaching losses are minimal and decrease quickly after fire or clearcutting, and soil fertility is improved. However, nutrient removals in harvested biomass can be quite high, particularly when whole tree harvests are combined with short rotations.

INTRODUCTION

Aspen stands became established over much of the northern Lake States following forest fires and logging of the white pines around the turn of the century. Aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) constitutes more than half of the Lake States' total pulpwood cut (Keays 1972). National domestic consumption plus exports of pulpwood rose steadily from 8.6 million cords in 1920 to 88.8 million cords in 1972, and are expected to rise to 178 million cords by the year 2000 (USDA 1974). Besides this increased demand for the more traditional forest products, the demand of forests for recreation use is also rising (Clausen 1978).

In order to meet these increased demands on decreased amounts of forest land, many timber companies and public foresters are considering managing current forest lands more intensively. Intensive management may include species conversion, stand improvement, and fertilization, but more often refers to the harvest of greater amounts of the aboveground biomass.

Intensive harvesting is expected to drain considerable amounts of nutrients from stands (Kimmins 1977). Rising energy costs make it unlikely that these losses can be offset economically by fertilization. It appears that forest managers will need to rely on the existing nutrient capital of the forest to "maintain continuous production" (Jorgensen et al. 1975). Proper use and conservation of this capital will rely on knowledge of the distribution and cycling of nutrients within the forest-soil ecosystem.

The major objective of this paper is to describe the nutrient cycles in aspen stands in comparison with associated upland forest types. Specific purposes of this review will be: (1) To acquaint the reader with the major findings of nutrient cycling research in aspen ecosystems. Particular emphasis will be placed on the biologic pattern of the cycle, especially the uptake and retention of nutrients by trees, and their return and incorporation into the soil by processes operating in the forest floor. (2) To compare the cycling of nutrients by aspen stands to cycling by other forest types collectively known

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as cool temperate forests. (3) To point out areas in the literature not yet fully addressed, or which have been recognized only recently. (4) To point out some ecological, silvicultural and pedological implications of nutrient cycling.

The cycling of nutrients in an ecosystem has both static and dynamic aspects. The static aspects are the distribution of organic matter and nutrients in the plant-forest floor-mineral soil system. The dynamic aspects are: (1) the inputs of nutrients by precipitation and weathering, (2) fluxes of nutrients between trees, forest floor, and mineral soil, and (3) outputs of nutrients by runoff or leaching.

DISTRIBUTION OF BIOMASS, ORGANIC MATTER, AND NUTRIENTS WITHIN THE ECOSYSTEM

Organic matter, or more generally biomass, of a forest ecosystem is generally greatest in vegetation, followed by the mineral soil and the forest floor (Curlin 1968). The relative amounts in the forest floor and mineral soil depend on whether the stand is coniferous or deciduous (MacLean and Wein 1977).

The biomass (i.e., weight of living vegetation) of cool temperate forests is generally between 100 and 200 t/ha (Whittaker and Marks 1975). Biomass of mature aspen stands in the Lake States is between 205 and 230 t/ha (Bray and Dudkiewicz 1963, Alban et al. 1978). A pole-size aspen stand in the Lake States has a biomass of approximately 100 t/ha (Crow 1978) while aspen stands on poor sites could have biomasses as low as 5 to 60 t/ha (Bray and Dudkiewicz 1963, James and Smith 1977) and mature aspen stands on productive sites could have biomasses approaching 250 t/ha (Pastor and Bockheim 1981, 1984).

The weight of the forest floor of cool temperate forests is generally less than 60 t/ha (Foster and Morrison 1976, Gosz et al. 1976, MacLean and Wein 1977) and is somewhat greater in conifer stands than hardwood stands (MacLean and Wein 1977). An Alaskan aspen stand had a mor floor which weighed 42 t/ha (Van Cleve and Noonan 1975). Mors beneath aspen stands in the Lake States weigh between 20 and 55 t/ha (Alway and Kittredge 1933, Stoeckeler 1961, Alban et al. 1978). In contrast, mulls beneath oak stands have been reported to weigh between 1.4 and 11 t/ha (Nielsen and Hole 1963, Lang and Formann 1978).

Within trees, the distribution of nutrients depends on both tissue concentration and tissue biomass. Concentrations of nutrients in most trees is greatest in leaves, followed by bark, branches, bole wood, and roots (Curlin 1968). In aspen, concentrations are highest in leaves, followed by current twigs, bark, branches, roots, dead branches, and finally bole wood (Young and Gunn 1966, Johnston and Bartos 1977). Biomass of most tree tissues is generally distributed in the order bole wood, roots, branches, bark, and leaves (Curlin 1968). Biomass of aspen trees is also distributed in this order, except that the weight of bark is generally greater than the weight of branches (Johnston and Bartos 1977, Alban et al. 1978, Crow 1978). Aspen bark contains the greatest amount of nutrients within the tree because of its relatively high biomass and nutrient concentrations, followed by roots, bole wood, branches, and leaves (Alban et al. 1978, Pastor and Bockheim 1984).

Total amounts of nutrients within trees is distributed in the order Ca,N > K > Mg > P (Curlin 1968). In deciduous trees, including aspen, the amount of Ca is greater than the amount of N, while in conifers N is greater than Ca (Foster and Morrison 1976, MacLean and Wein 1977, Alban et al. 1978).

The relative amounts of nutrients within the forest floor and amounts of available nutrients within the mineral soil follows the same distribution as in trees (Cole et al. 1967, Alban et al. 1978). However, the distribution of nutrients in a total elemental analysis of soil reflects that of the initial material, generally K >> Ca > Mg >> P > N (Barth 1961, Johnson et al. 1968, Foster and Morrison 1976). Amounts of organic matter and nutrients within aspen forest floors are greater in the H layer, if present, followed by the F and L layers (Stoeckeler 1961, Van Cleve and Noonan 1976, Lang and Forman 1978). Concentrations of nutrients within the mineral soil are usually highest within the A1, if present, but the bulk density and thickness of the B horizon result in its having the greatest amount of nutrients in aspen as well as other stands (Cole et al. 1967, Foster and Morrison 1976, Alban et al. 1978).

INPUTS OF NUTRIENTS TO A FOREST ECOSYSTEM

Inputs of nutrients to a forest ecosystem are by weathering of the soil, precipitation, and atmospheric fixation. The latter, while important as a source of nitrogen and sulfur (Likens et al. 1977), is difficult to measure and represents an unknown quantity in most nutrient cycling studies. For most nutrients, precipitation and weathering are the main sources.

PRECIPITATION

For most nutrients, the input by precipitation is less than the input by weathering. Yet, precipitation may annually contribute nutrient amounts equal to those tied up annually in the bole (Ovington 1962). Concentrations of nutrients in precipitation in the Northeast are generally less than 1 mg/l, except for sulfate, which can be as high as 3 mg/l (Eaton et al. 1973). In the Lake States concentrations are slightly higher (Comerford and White 1977, Verry and Timmons 1977). These higher concentrations may be the result of agricultural activity (Fisher 1968). Vitousek (1977) and Cronan and others (1978) found precipitation chemistry to control the concentrations of chloride and sulfate within the ecosystem.

WEATHERING

Weathering is especially important in the supply of cations in forms available for plant uptake. Weathering in a nutrient cycling context has been studied most successfully by using an equation of Barth (1961):

$$W = \frac{D}{C - S}$$

Where W is the amount of rock weathered per unit time over unit land surface; D is cation output in the same units; C is percent of element in unweathered material, and S is percent of element in weathered material. Johnson et al. (1968), using streamwater fluxes for D, A2 concentrations for S, and bedrock concentrations for C, calculate that approximately 800 kg/ha of initial material are weathered per year in New England. This equation assumes that there are no sinks within the ecosystem, such as vegetation or the exchange complex of the soil, where nutrients can accumulate. Ignoring such sinks underestimates weathering rates by a factor of two or more (Likens et al. 1977). By taking the vegetation sink into account in a mass balance estimate of weathering, Likens and others (1977) calculate annual supply of cations by weathering of a spodosol to be 21.1 kg/ha Ca, 7.1 kg/ha K, 5.8 kg/ha Na, and 3.5 kg/ha Mg.

This approach does not work for aspen ecosystems because the large uptake and retention rates, to be discussed further below, distort the calculations and lead to unrealistically high estimates (Pastor and Bockheim 1984). By leaching columns of soil with aspen leaf litter extracts, Adams and Boyle (1979) estimated weathering rates of less than 1 kg/ha per year apiece for calcium and magnesium and 4 kg/ha per year for potassium. However, this begs the question of what are the sources of these nutrients for annual uptake if not weathering. The most likely explanation is that suggested by data of Alban (1982), namely that nutrients are accumulating in vegetation at the expense of their exchangeable pools in the soil. In addition, an unknown but potentially large portion of calcium in aspen may be as calcium oxalate, particularly in bark. Calcium oxalate, also produced by soil fungi, is easily weathered and speeds weathering of other soil minerals and increases nutrient availability to vegetation (Graustein et al. 1977). Further research on weathering rates in aspen stands should focus on the formation and dissolution of calcium oxalate and its interactions with calcium and other nutrients.

NUTRIENT FLUXES WITHIN THE ECOSYSTEM

PLANT UPTAKE AND RETENTION OF NUTRIENTS, AND PRODUCTION OF DRY MATTER

Production of dry matter is usually considered along with biomass in the literature. In this review, production is not considered along with biomass, but with nutrient uptake by trees because the dynamics of nutrient uptake is directly related to the dynamics of tree growth (Curlin 1968). Whittaker and Marks (1975) give a range of 4.5 to 24 t/ha annual dry matter production in cool temperate forests, with a mean of around 10 t/ha. Annual production of dry matter by aspen stands in the Lake States ranges from 4 t/ha on a poor site to 12.5 t/ha on good sites (Bray and Dudkiewicz 1963, Crow 1978, Pastor and Bockheim 1984).

The rate of dry matter production changes during the life of a stand, the greatest rate of production being in pole-size stands (Ovington 1962, Lieth 1974) or even in younger stands (Marks 1974). As a tree grows, production is increasingly concentrated in leaves and branches (Whittaker et al. 1974). In most trees, including aspen, production of dry matter by leaves is greatest, followed by wood, branches, roots, bark, and fruits (Whittaker and Marks 1972, Crow 1978).

Most of the nutrient uptake of a tree is directed into metabolically active tissues, such as leaves and branches (Woodwell et al. 1975). In contrast to many other species, aspen bark is also metabolically active because of its photosynthetic capability (Pearson and Lawrence 1958). Uptake of nutrients in northern hardwoods, and in trees in general, follows the order: N,Ca > K > Na > S > Mg > P (Likens et al. 1977). Uptake by European aspen (P. tremula) and quaking aspen follow this pattern except that the uptake of Ca is greater than N (Rodin and Bazilevich 1965, Pastor and Bockheim 1984). In addition, aspen in Wisconsin accumulates zinc in amounts seven times higher than the minimum required by most plants (Gerloff et al. 1966). Much research remains to be done on nutrient uptake by aspen, especially in relation to soil fertility.

In most forests, approximately 50 to 80 percent of annual uptake is returned to the soil by litterfall, throughfall, and stemflow (Curlin 1968, Duvigneaud and Denaeyer-De Smet 1970). In contrast, aspen returns less than half the annual uptake of each nutrient and is particularly efficient at retaining calcium, sulfur and zinc, especially in bark (Alban et al. 1978, Pastor and Bockheim 1984). Mean annual nutrient retention by aspen in Minnesota was found to be 21.4 kg Ca/ha, 9.2 kg N/ha, 7.2 kg K/ha, 1.4 kg Mg/ha, and 1.2 kg P/ha (Alban et al. 1978). Even greater retention rates have been reported for an aspen-maple forest in Wisconsin (Pastor and Bockheim 1984).

THROUGHFALL

Throughfall returns less nutrients to the soil than litter but more than stemflow (Curlin 1968, Duvigneaud and Denaeyer-De Smet 1970). The only exception is K, for which throughfall is the principal return mechanism (Cole et al. 1967, Cromack and Monk 1975, Foster and Morrison 1976). In general, nutrients are leached from the leaves in the order S > K > Ca,N,Mg > P (Curlin 1968, Eaton et al. 1973, Gosz et al. 1975). Aspen (Verry and Timmons 1977) and birch (Comerford and White 1977) throughfall is especially high in calcium, reflecting the high concentrations of Ca in the leaves (Young and Gunn 1966). Aspen leaves may take up ammonium and nitrate directly from rain, decreasing their concentrations in throughfall compared to precipitation (Timmons et al. 1977, Pastor and Bockheim 1984).

STEMFLOW

The amount of water flowing down the boles of trees is generally less than 5 percent of the total rainfall, and the amount of nutrients returned by stemflow is less than 10 percent of that returned by throughfall and stemflow combined (Eaton et al. 1973, Foster and Morrison 1976). Stemflow concentrations, however, are generally two to three times higher than throughfall concentrations (Voigt 1960). Stemflow from aspen is especially rich in Ca, Mg, and K, and returns substantial amounts of these nutrients to the soil (Mahendrappa 1974, Verry and Timmons 1977). The concentrations of nutrients in stemflow are influenced by species, bark roughness, rainfall intensity, and mosses and lichens growing on the bole (Eaton et al. 1973, Patterson 1975). Stemflow may cause high concentrations of nutrients in the soil near the bole of the tree (Gersper and Holowaychuk 1971, Patterson 1975), although it is difficult to separate these effects of stemflow from similar effects of bark litter (Zinke 1962).

LITTER

Except for potassium, litterfall is the major pathway by which nutrients are returned to the soil (Curlin 1968). The pronounced autumn litterfall in cool temperate forests is the most dramatic aspect of nutrient cycling. Annual litter production ranges from 1 t/ha for Arctic-Alpine environments to 11 t/ha for Equatorial forests, with cool temperate forests having a mean of 3.5 t/ha (Bray and Gorham 1964). Leaves constitute up to 70 percent of total litterfall, branches 12 to 22 percent, bark 1 to 14 percent, and miscellaneous plant parts up to 10 percent (Bray and Gorham 1964, Gosz et al. 1972). Branch litterfall can constitute a higher proportion of the total litter in old-growth oak stands (Lang and Forman 1978) or in aspen stands in advanced stages of deterioration (Graham et al. 1963). Leaffall in a mature Alaskan aspen stand is approximately 1.9 t/ha per year (Van Cleve and Noonan 1975), while in the Lake States aspen leaffall ranges between 1.4 and 4.5 t/ha per year (Stoeckeler 1961).

Nitrogen, calcium and potassium made up 81 percent of the total amount of nutrients returned in litterfall in a northern hardwoods stand (Gosz et al. 1972). Other nutrients are returned in the order Mg > S > P > Zn. Aspen litterfall is especially high in Ca (Stoeckeler 1961, Van Cleve and Noonan 1975) and zinc (Van Cleve and Noonan 1975).

DECOMPOSITION AND INCORPORATION OF NUTRIENTS INTO SOIL

The forest floor and decomposition therein play an active role in the nutrient cycle because the processes of incorporation of litter into the soil take place in the floor and because the floor has a high permeability, permitting precipitation to infiltrate the soil. The soil organic matter, of which the forest floor is a major part, is a large pool through which nutrients cycle slowly, and as such regulates the flow of nutrients in a forest ecosystem (O'Neill et al. 1975, Gosz et al. 1976).

Decomposition of aspen leaf litter is more rapid than spruce in boreal forests but less rapid than maple in northern hardwood forests (Flanagan and Van Cleve 1983, McClaugherty et al. 1985). This appears to be because of the moderate amounts of lignin in aspen leaf litter, compared with low amounts in maple and much greater amounts in spruce (Flanagan and Van Cleve 1983, McClaugherty et al. 1985, Pastor and Post 1986).

Aber and Melillo (1980) have proposed a three-stage theory of decomposition which unifies previous theories: (1) an initial period in which nutrients are leached from litter; (2) a period of active decomposition of tissues; and (3) a final period in which nutrients involved in microbial respiration are flushed from the system.

The initial leaching stage is probably very rapid (Aber and Melillo, 1978). Evidence is provided by Melin (1930), Nykvist (1959) and Gosz and others (1975). The removal of water soluble substances may be especially important in the decomposition of bigtooth aspen (P. grandidentata) leaves (Melin 1930).

The behavior of various elements varies during the second stage, depending on mobility, availability to microorganisms, and place in leaf tissue. Nitrogen and phosphorus, being in short supply to microbes, are immobilized during the first half of this stage as the microbes decompose organic compounds (Lutz and Chandler 1946, Gosz et al. 1973, Aber and Melillo 1978). Aspen leaves have unusually high nitrogen immobilization rates, exceeding 9.5 mg nitrogen per g total mass loss during decay (McClaugherty et al. 1985). Of species that normally grow with aspen, this is exceeded only by spruce (Pastor and Post 1986). Therefore, immobilization of nitrogen by microbes decomposing aspen leaf litter represent a secondary retention mechanism within the aspen ecosystem.

Once mineralization begins during decomposition, Curlin (1968) gives the rate of release of nutrients from decomposing tissue as K > P > Ca = N. Gosz and others (1973) found Mg to be released most rapidly from sugar maple litter, followed by K, S, Ca, N, and P. Nutrients are released from aspen leaves in Alaska in the order K, Ca, Mg, Zn, P, N, and Fe (Van Cleve and Noonan 1975).

Animals, especially earthworms (Lumbricus terrestris), can greatly increase decomposition of litter by disintegration of tissues, increasing tissue surface area, chemical digestion, mixing organic matter with mineral soil, and dispersing microorganisms (Nielsen and Hole 1963, Witkamp and Crossley 1966, Edwards et al. 1970, Jensen 1974). Animals important in aspen floors include mites, spring tails, flies, and beetles (Wagner et al. 1977, Mitchell 1978) and possibly earthworms (Bleak 1970).

Decomposition of wood is much slower than that of leaves. In the first year after sugar maple, yellow birch, and beech branches were deposited on the soil surface, Gosz and others (1973) found little or no weight loss except that caused by bark sloughing. The slow decomposition of wood is ascribed to its high C:N ratio (Lutz and Chandler 1946) which results in immobilization of N during wood decomposition (Allison and Murphy 1962, Allison et al. 1963). Wood can be important sites of nitrogen-fixation (Cornaby and Waide 1963). Lang and Forman (1978) say that, because of its slow decomposition and high C:N ratio, woody detritus can be an important buffer in the cycling of nutrients. Despite the recognized importance of woody detritus to nutrient cycling, there have been no studies to date on natural decay of aspen wood and bark.

MOVEMENT OF NUTRIENTS DOWNWARD INTO THE SOIL PROFILE

Once nutrients are released from decomposed tissue, they can be taken up by plants, and enter the biologic cycle again, or they can move downward into the profile in solution. Except for stemflow, the maximum concentrations of nutrients in solution occur as water passes through the forest floor (Cole et al. 1967, Best and Monk 1975, Feller 1977).

In a series of papers, McColl studied the aqueous transfer of nutrients from the floor to the mineral soil (McColl 1972, 1973a,b). Using electrical conductivity of the solution as an index of total nutrient content, McColl found that nutrient movement from the floor depends on total water flow, the length of the dry period preceding flushing, and the temperature of the dry period. The last two factors relate to the rate of decomposition of the organic matter. McColl (1973b) proposed that the concentration of nutrients in soil solution is determined by the forest floor where biologic activity is the greatest and that "concomitant changes occur as the solution passes through the solum." Also, the solution characteristics of a given horizon are largely determined by the horizon above it (McColl 1973b).

Seasonal variation in microbial and plant uptake cause seasonal variations in nutrient content of soil water. McColl (1972) and Feller (1977) found electrical conductivity and nutrient concentrations of water draining from the forest floor of Douglas fir stands to be highest in late summer. On the other hand, Remezov (1958) found concentrations of nutrients in both soil water and mineral soil to be highest in the spring and lowest in late summer beneath an aspen (P. tremula) stand. In all three cases, this was ascribed to seasonal patterns of litter decomposition.

Remezov (1958) found annual leaching losses from an aspen (P. tremula) forest floor to be 85.3 kg Ca/ha, 42.7 kg K/ha, 31.7 kg N/ha, 21.0 kg Si/ha, 9.9 kg P/ha, and 6.0 kg Al/ha. Remezov (1958) and Timmons and others (1977) suggest that the forest floor and mineral soil beneath aspen stands are important sinks for nutrients as they move downward in solution.

NUTRIENT OUTPUTS

To one degree or another, outputs of nutrients from a forest are dependent on the inputs and cycling of nutrients within the forest Outputs are small in relation to annual uptake by plants (Cole et al. 1967, Likens et al. 1977) indicating that forests possess efficient cycling and storage mechanisms (Likens et al. 1977). Outputs of nutrients in runoff is generally small because of the high permeability of the forest floor (Likens et al. 1969) and most nutrient output is by leaching beyond the rooting zone.

Likens and others (1969) stress the role of the hydrologic cycle in controlling leaching losses. Johnson and others (1969) propose a model in which concentration of nutrients in solution is inversely related to water flux but directly related to residence time of water in the ecosystem, and the concentrations of nutrients in soil water and rainwater. Johnson and Swank (1973) found concentrations of nutrients in leachate fluctuate independently of flow rate, and propose biologic control rather than hydrologic control. Remezov (1958) observed "no direct relation between the volume of drainage and the total amount of Ca ... and K lost from soil [in an oak stand]." Vitousek and Reiners (1975) and Vitousek (1977) showed that nutrient losses are inversely related to the rate at which each nutrient is accumulated in growing biomass.

Concentrations of nutrients in leachate from a northern hardwood forest decrease in the order SO_4, Ca, NO_3, Na, Cl, Mg, K, NH_4. Concentrations in leachate from a Douglas fir stand decrease in the order Ca, K, N, P (Cole et al. 1967). In contrast, concentrations of calcium in leachate from aspen stands are higher than in leachate from other stands, while nitrogen is much lower (Verry 1972, Richardson and Lund 1975, Timmons et al. 1977, Pastor and Bockheim 1984). On the other hand, Remezov (1958) observed N concentrations in water draining from aspen (P. tremula) stands to be similar to those in water draining from oak stands. Concentrations of nutrients in leachate from soils beneath aspen stands are in the order Ca > Mg > Na,K > NO_3 > NH_4 (Remezov 1958, Verry 1972, Richardson and Lund 1975, Timmons et al. 1977, Pastor and Bockheim 1984). In contrast, larger amounts of nutrients can be lost during snowmelt in aspen stands, mainly because the trees are not actively taking up nutrients in late winter (Timmons et al. 1977).

SOME ECOLOGICAL AND SILVICULTURAL IMPLICATIONS OF NUTRIENT CYCLING

ECOLOGICAL IMPLICATIONS

Odum (1969) considered nutrient cycling to be related to the successional status of a stand. He proposed that climax forests are stable in part because they cycle nutrients efficiently, while successional stands are unstable because they "leak" nutrients. However, a number of recent studies indicate that early successional stands of pin cherry (Prunus pensylvanica Ehr.) and aspen tie up nutrients in rapidly growing biomass and thereby lose less through leaching than climax stands (Marks and Bormann 1972, Marks 1974, Vitousek and Reiners 1975, Richardson and Lund 1975).

In recent years, the cycling of nutrients by plants has come to be regarded as part of the species niche, that is, the "multi-dimensional space representative of the environment in which a species exhibits positive fitness" (Garten 1978). Woodwell and others (1975) and Gerloff and others (1966) allude to niche differentiation as a process leading to species differences in nutrient concentrations in tissues. Using multivariate analytical techniques, Garten (1978) found floodplain species to be dispersed in a "tissue concentration space" and interpreted this as one aspect of the species' niches. In particular, species were most different with regard to their ability to take up and store K, which was in low supply in these soils. Monk (1966) and Day and McGinty (1975) proposed that species differences in nutrient cycling allows species to maximize utilization of soil nutrient reserves. They also suggested that the different ways in which species cycle nutrients underlie ecosystem structure. The ability of aspen to accumulate large amounts of zinc and other trace elements (Gerloff et al. 1966) may be one reason why aspen can survive on mine spoil banks where few other species can (Leisman 1957). Pastor and Bockheim (1984) found that productive aspen-maple ecosystems in Wisconsin retain large amounts of nutrients because of aspen's ability to take up large quantities of nutrients and maple's ability to cycle nutrients in the shade of aspen.

The role of nutrient cycling in soil genesis has received much attention in Europe as a result of the biogeocoenose concept (Remezov and Pogrebnyak 1965). Until recently in America, soil genesis has had a strong mineralogical flavor. A notable exception is the Soil Survey of Menominee County (Milfred et al. 1967), in which soil differences between hemlock and maple stands are related to differences in nutrient content of throughfall and litter, among other factors. Mention has been made above of the ability of aspen to extract nutrients from subsoil and redistribute them to the top of the soil, but this is another area in which fruitful research could be done.

SILVICULTURAL IMPLICATIONS

It has been shown repeatedly that aspen cycles large amounts of Ca, Mg, N, and Zn in litterfall, throughfall and stemflow, and uptake (Van Cleve and Noonan 1975, Verry and Timmons 1977, Alban et al. 1978). Not surprisingly, growth and site index (height at a reference age) of aspen have been correlated with the nutrient content of the soil, especially Ca, but also Mg and N (Kittredge 1938, Voigt et al. 1957, Stoeckeler 1960, Fralish and Loucks 1975). Growth has also been correlated with physical properties of the soil, especially those leading to greater moisture retention such as water holding capacity, silt + clay content, and presence of pans (Kittredge 1938, Stoeckeler 1960, Graham et al. 1963, Fralish and Loucks 1975). While this has been interpreted as indicating the demand of aspen for water, it should also be noted that these properties also decrease loss of nutrients by leaching.

The life history of aspen has been reviewed by Graham and others (1963), Fowells (1965) and Brinkman and Roe (1975). Aspen reproduces most commonly by root sprouting of suckers after fire, logging, or other disturbance and the establishment of these sucker stands is the silvicultural basis for clearcutting aspen (Graham et al. 1963). From the standpoint of nutrient cycling, the rapid and dense growth of aspen sucker stands may ameliorate leaching loss (Richardson and Lund 1975).

Mortality is high in the first few years, and stands go through several periods of natural thinning. After 50 to 60 years, the aspen stand deteriorates because of disease. Stand break-up is very rapid, often less than five years (Graham et al. 1963, Fralish and Loucks 1975). Break-up may be delayed on sites high in nutrients (Graham et al. 1963). On good sites in the Lake States, aspen is succeeded by northern hardwoods, especially sugar maple, while on poor sites a second sucker stand may sprout, or aspen may be replaced by brush species (Kittredge 1938, Fralish 1975). A key unresolved question in aspen nutrient cycling research is how the different nutrient cycles are reorganized after the return of two thirds of aboveground biomass to the soil within the five years it takes for a stand to break up, and how the reorganization of the nutrient cycles by the succeeding species affect subsequent stand productivity. To date, there have been no studies that have followed a single stand through the breakup phase into the succeeding generation.

Theoretically, to the extent that the succeeding species cycle nutrients differently than aspen, soil properties and productivity will be altered as succession proceeds (Pastor and Post 1986). Thus, as we consider the effect of different species on nutrient cycles, especially the cycles of the more limiting nutrients such as nitrogen, the concept of site index as a fixed estimate of site quality becomes less tenable. For example, aspen has been called a "soil improver" (Stoeckeler 1961) in that it replenishes nutrients to the soil surface, allowing more demanding species, such as sugar maple (Farnsworth and Leaf 1963, Post 1968) to succeed it. As with aspen growth, sugar maple growth is influenced by physical properties of the soil (Westveld 1933), but growth has also been correlated with total soil nitrogen and exchangeable magnesium (Post 1968). In contrast, the succession of aspen to spruce in boreal forests may cause soil nitrogen availability to decline because of the slower decay and greater immobilization of nitrogen by spruce litter; model simulations show that spruce dieback may result (Pastor et al. 1987). Thus the growth of species that succeed aspen depends to a great extent on what aspen did to the soil during its previous occupancy and how these properties are subsequently modified by the succeeding species.

Concern for water quality and maintenance of forest productivity has led to increased research in the effects of harvesting on nutrient cycling (Cole and Gessel 1965, Likens et al. 1970, Johnson and Swank 1973). The two major effects of harvesting on nutrient cycling are increased loss of nutrients by leaching and removal of nutrients in harvested biomass.

Following deforestation of a northern hardwoods stand in New Hampshire, Likens and others (1970) observed up to sixty-fold increases in NO_3^- concentrations in streamwater draining the stand. This was accompanied by increased nitrification and decomposition of the forest floor (Smith et al. 1968, Likens et al. 1969). Increased nitrification and decomposition produced more H^+ which replaced cations on exchange sites, thereby causing increased leaching losses of other ions (Likens et al. 1969, McColl 1972). Sulfate losses, however, decreased after deforestation (Likens et al. 1969, 1970). This may be due to the toxic effects of nitrate on Thiobacillus thiooxidans, a sulfur oxidizing bacterium (Likens et al. 1969) or to decreased fixation of atmospheric SO_2 by plants (Hoeft et al. 1972). Reduced evapotranspiration by plants after cutting led to increased water losses through runoff and leaching, as well as increased nutrient losses (Likens et al. 1970). Vitousek (1977) showed that reduced plant uptake, as well as nitrification, can also lead to increased nutrient loss.

Less drastic changes may occur with more conventional management practices (Ovington 1960, Patric and Smith, 1975). Losses from conventional clearcuts in New England followed the same pattern as losses from the deforested area, but were not as high (Pierce et al. 1972). In other areas, clearcutting, including clearcutting of aspen, did not appreciably affect water quality of nutrient losses by leaching (Cole and Gessel 1965, Verry 1972, Fredricksen et al. 1975, Richardson and Lund 1975). This is most likely due to plant uptake by regrowth (Marks 1974, Richardson and Lund 1975). Species conversion, thinning, and selective cutting may decrease nutrient losses by causing transfer of nutrients to more vigorous trees (Ovington 1960, Johnson and Swank 1973).

The recovery of an ecosystem from harvesting may depend on plant growth and on the type of harvesting. Leaching losses can return to control levels after two years or less (Likens et al. 1978), primarily because of increased plant uptake (Marks and Bormann 1972, Marks 1974, Bormann et al. 1974, Vitousek and Reiners 1975, Henderson and Harris 1975, Richardson and Lund 1975).

Aber and others (1978) suggest that the pattern of recovery is different following removal of the entire aboveground biomass ("whole-tree harvesting") than following conventional clearcutting, in which only the bole is removed. This is due to the presence or absence of slash:

> ...dead wood acts as an important buffer, minimizing nitrogen losses immediately after cutting by providing a carbon-rich substrate for immobilization of nitrogen by microbes and then gradually giving this nitrogen back through its slow rate of decomposition.

Their model showed decreasing amounts of available N in the floor following successive whole-tree harvests at short rotation. A model by Waide and Swank (1975) predicts reduced yields following whole-tree harvesting, primarily for the same reason. Williams and Mace (1975) investigated a whole-tree harvest and conventional clearcut and found nitrogen immobilization in the floor of the clearcut and high nitrate losses by leaching from the floor of the whole-tree harvested area. However, they also found greater nitrification and N losses at depth in the soil of the clearcut compared to the whole-tree harvest. They attributed this to greater soil compaction in the clearcut which increased soil temperature and water retention, resulting in turn in increased microbial growth at depth in the soil.

Nutrient removals in harvested biomass are drains on the nutrient reserves of managed forests. These removals are not thought to be significant in relation to soil nutrient reserves for selection, thinning, or even harvesting of all tree boles (Ovington 1960, Patric and Smith 1975). However, whole-tree harvesting and short rotations (30 years or less) remove substantially more nutrients because a great deal of nutrients are stored in tree crowns (Boyle and Ek 1972, Weetman and Webber 1972, White 1974). These losses can be as much as five times as great for whole-tree harvesting as compared to conventional bole harvesting (Mälkönen 1973). Boyle and Ek (1972) suggested that calcium would limit aspen growth only after nine, 30-year whole-tree harvests. However, Alban and others (1978) suggested that one whole-tree harvest of a mature aspen stand might severely deplete the site of K and P. In the Lake States, nitrogen is the most limiting nutrient to aspen productivity. Pastor and Bockheim (1984) found 350 kg of N per ha in aboveground biomass of a mature aspen stand at culmination of mean annual increment, and inputs in precipitation of approximately 5 kg per ha per year. If all 350 kg were removed in a complete whole tree harvest, then 60 years would be required to replenish this amount in the soil nitrogen pool. Thus, 60 years, or the amount removed in harvested biomass divided by input rates, could be thought of as the sustainable rotation age; rotations shorter than this would presumably lead eventually to nutrient depletion and losses of productivity.

Kimmins (1977) proposes several questions which must be answered before the effects of whole-tree harvesting can be fully evaluated, including: (1) What proportion of site nutrient reserves are removed in biomass? (2) What are the size of reserves in the soil? (3) How rapidly do nutrients cycle after harvesting? (4) How rapid are nutrients removed in harvesting replenished by weathering and other inputs? (5) What are the nutrient requirements of succeeding crops? (6) How great are other harvest-induced losses, such as erosion or leaching?

Except for the study of Williams and Mace (1975) and the models proposed by Aber and others (1978) and Waide and Swank (1975), little work has been done on the actual cycling of nutrients in intensively-harvested stands. Not surprisingly, this has led to considerable disagreement on the possible effects of whole-tree harvesting and short rotation on future stand productivity. However, it is clear that the intensification of aspen stand management cannot be sustained without due consideration given to the distinct manner that aspen cycles nutrients in contrast to associated and succeeding species, and the effects of different harvesting regimes on nutrient distributions and flows.

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SILVICULTURE AND MANAGEMENT OF ASPEN IN CANADA: THE WESTERN CANADA SCENE

S. Navratil, I.E. Bella, and E.B. Peterson[1]

ABSTRACT.--After a brief review of the aspen resource in British Columbia, Alberta, Saskatchewan and Manitoba, and highlights of recent trends in aspen utilization, the paper reviews aspen regeneration and silviculture, density management, growth and yield predictions, and present and future challenges in aspen management. The future of the aspen resource in relation to industrial development, silvicultural practices and possible greenhouse effects are also covered.

INTRODUCTION

For clarification purposes a summary of the contents of this paper follow:

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[1]S. Navratil and I.E. Bella, Forestry Canada, Northern Forestry Centre, Edmonton, Alberta, T6H 3S5, Canada, and E.B. Peterson, Western Ecological Services Ltd., Victoria, B.C., V8N 1G2, Canada

At the 1972 Aspen symposium Dr. Keays (Keays 1972) in his leading paper suggested that in Canada:

> the aspen cut is small and is not increasing appreciably. No change in this trend is anticipated in the near future. Even by the turn of the century it is likely that less than half of Canada's annual allowable cut of aspen will be utilized.

The last few years are proving this to be an understatement. Indeed, the rapid increase in aspen utilization, particularly in western Canada, far exceeded most of our expectations.

As a result, aspen is no longer considered a weed species. Quite the contrary, aspen in the west is now heralded as the "Queen of the forests," the "champion species," and the "star of mixedwood management."

One thing did not change; Canada still has an abundant aspen resource of about 2981 million m^3 growing stock, and an estimated Annual Allowable Cut (AAC) of about 45 million m^3 -- other hardwoods make up another 15 million m^3. The four western provinces -- British Columbia, Alberta, Saskatchewan, and Manitoba -- together have 16.3 million m^3, or about one third of the country's AAC; with Alberta contributing about one half of this (Fig. 1).

In this paper we synthesize the latest information available on aspen regeneration and silviculture and problems and challenges in growing this crop, then speculate about the future of aspen management in western Canada.

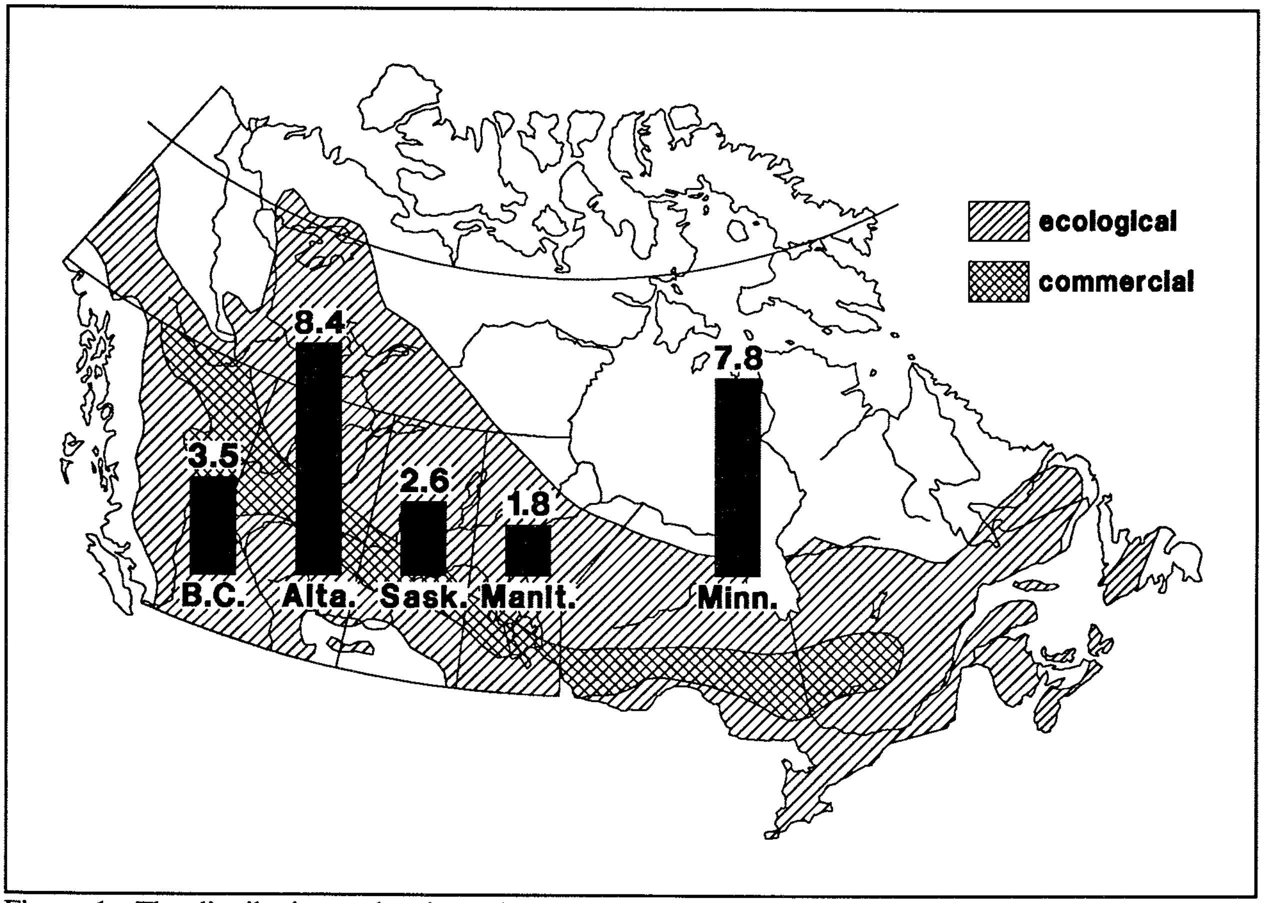

Figure 1.--The distribution and estimated annual allowable cut of aspen in the four western provinces.

AFTER HARVESTING HARDWOOD STANDS

In western Canada, large scale harvesting of aspen stands started in the 1960s for flakeboard manufacturing in east central Saskatchewan. In that area, the harvested stands were almost pure aspen, growing largely on fairly level lacustrine deposits. Clearcutting was done throughout the year with wetter sites scheduled for winter harvest. Falling and delimbing with chainsaws and full-tree skidding with tractors in the 1960s and 1970s caused little soil compaction and root disturbance and generally resulted in adequate sucker density and stocking and no substantial problems in aspen regeneration.

In the same area, a research study (Bella and DeFranceschi 1972, Bella 1986) found excellent stocking (nearly 100%), and aspen density ranging from 50,000 to 150,000 suckers/ha. Large initial differences in densities due to season of logging (viz., winter or summer) and slash load diminished to a narrow range 5 years after harvest. The results implied flexibility in harvest scheduling and method of logging. Observations from other areas in the boreal forests of western Canada confirmed the relative ease of obtaining adequate aspen regeneration after clearcutting pure aspen stands on fresh upland sites.

General guidelines for regenerating aspen stands, and silvicultural manipulation of aspen clones were worked out in the region in the early 1970s (Steneker and Wall 1970, Steneker 1974, 1976). Much additional information about aspen silviculture and management is available in review and research papers from other regions in Canada and the United States (e.g., Doucet 1989, Davison et al. 1988, Debyle and Winokur 1985, Perala 1977). In the last 10-15 years, most information on aspen silviculture was concerned with its density control and its competition with conifer reproduction (e.g., Johnson 1986). Information on aspen regeneration within a regional context is covered by Steneker (1976) and Navratil and Bella (1989). Currently, Forestry Canada, Northern Forestry Centre, Edmonton, is compiling all available knowledge on aspen management in a monograph to be published in December 1989 (Peterson and Peterson 1990).

There are some factors in aspen regeneration that appear to be particularly important in western Canada's mixedwood forests. Among these, soil temperature and practices affecting it, may be the most important. In this region with cold soils, the removal of shrub layers by summer logging raises soil temperature, and as a result seems to enhance suckering and initial sucker density (Bella 1986). In stands with a heavy shrub layer, full tree logging and anchor chain treatment will destroy shrubs and reduce soil shading (Steneker 1976). Schier (1976) suggests that in northern areas, soil temperature may be more critical to aspen reproduction than carbohydrate reserves, which are important in the warmer, southern regions. These differences may explain conflicting recommendations concerning the beneficial effect of winter harvesting on density of aspen sucker regeneration (Heeney et al. 1975).

Improvements in Aspen Regeneration

Some problems in aspen regeneration have been observed on upland hardwood sites. Multiaged, patchy aspen regeneration after high grading, unexplained differences in aspen density in response to site treatments, and insufficient stocking of aspen regeneration ascribed to soil compaction and root disturbance from logging have all been noted to a variable degree in the region.

The recent upsurge in logging of several cover types that contain aspen has increased the awareness of aspen reproduction and the need for improved management in the region. Forest managers have come to realize that satisfactory aspen regeneration may not be free after all, and aspen regeneration may even need to be encouraged (Smith 1989). It should also be noted that widespread harvesting of the aspen resource, particularly in mixedwood stands, is so recent that only a few regionally specific problems have been identified. Appropriate regeneration strategies and silviculture methods are yet to be developed, or adopted from other regions. A survey of the aspen-using industry and the provincial governments in the region suggests broad support for improvement of aspen regeneration and for more intensive management of the aspen resource generally.

In most of western Canada, the majority of "pure" aspen cover types consist of mixed aspen-balsam poplar stands. At present, the demand and harvest of balsam poplar is rather limited, resulting in substantial amounts - as much as one third of the original basal area - of residual poplar left standing in aspen cutovers (Peterson et al. 1989, Peterson 1988, Denney 1987). The presence of these poplars hinders aspen suckering and site preparation, and will likely increase balsam poplar regeneration while slowing aspen sucker growth. Detailed regeneration surveys are required to fully assess the impact of residual balsam poplar. Other issues and challenges of balsam poplar management in the context of aspen management are addressed later in this paper.

The past practice in some areas of removing superior aspen trees (high grading), resulted in aspen stands with uneven aged structure, irregular and poor regeneration, and abundant brush layer. There is a similar situation in overmature, decadent hardwood stands that also lack vigorous aspen regeneration. Past underutilization and efficient fire protection have shifted age class distribution of aspen and mixedwood stands towards older age classes. The challenges of rejuvenating high-graded and overmature stands, and their successful regeneration and rehabilitation to full production are discussed later.

Locally observed problems of inadequate aspen regeneration related to logging are easy to rectify. Forest managers in the region are aware of these problems and intend to adopt harvesting schedules and methods that limit soil compaction and root disturbance (unpublished survey by the authors). Landings lacking aspen regrowth are planted with conifer seedlings to maintain forest production, as well as to improve aesthetic values and increase ecological diversity. Planting of native or superior aspen and hybrid poplar is anticipated when production of poplar and aspen planting stock becomes justified and available (Smith 1989).

AFTER HARVESTING MIXEDWOOD STANDS

More serious problems, as well as land use conflicts relating to aspen regeneration and management, emerge where aspen is harvested in mixedwood stands. In the Boreal Mixedwood Region, aspen grows in admixtures with other species; aspen-pine (jack or lodgepole) and aspen-spruce (primarily white spruce) are the most important in this review. On a regional basis, approximately 30 percent of aspen AAC is in the mixedwood cover types. On a productive land area basis, the proportion of aspen can be much higher - e.g., in Alberta 50 percent of the productive land area that supports aspen is in mixedwood stands (Clark 1988).

Mixedwood cover types occur over a wide range of moisture regimes, soil textures, and organic layer thicknesses, all of which affect, either directly or indirectly, density and growth of aspen regeneration through effects on soil temperature and herbaceous and shrub cover. Often on the most productive mixedwood sites, a thick duff layer, a rise in the water table after harvest, low soil temperature and invasion of alder and willow competition may hinder aspen regeneration. On such sites, the balsam poplar component often increases compared to the original stand (pers. comm. R. Brooks, D. Sidders, 1989).

In this context, ecologically based site classification that also incorporates soil moisture dynamics may be particularly useful in mixedwood management, because aspen productivity and stand response to logging, site preparation, and regeneration practices are all site-related and predictable (Corns 1988). Ecological site classification systems that include some management and silvicultural interpretations pertinent to aspen regeneration, productivity, and competition are available for some areas in the region: e.g., for west central Alberta (Corns and Annas 1986) and for northeast British Columbia (DeLong 1988).

With increased aspen-mixedwood utilization, management regimes and guidelines for the renewal of mixedwood stands are currently the subject of reviews, discussions, and modifications (Beck et al. 1989, Henderson 1988). Policies relating to forest renewal have been historically biased in favor of conifers. These now have to recognize that aspen and other hardwoods are used and have value. Aspen regeneration objectives thus ought to be reflected in forest management goals and depend on whether aspen regeneration is to be encouraged as a future hardwood resource, tolerated, or suppressed in favor of mixed or conifer regeneration. The issues affecting the choice of aspen regeneration strategy encompass biological considerations such as site productivity potential for the species and regeneration performance, as well as policy and regulation issues.

Prediction of Aspen Regeneration After Harvesting Mixedwood Stands

Foresters making decisions concerning the regeneration phase of mixedwood stands need to predict the density of future aspen regeneration after the present stand is harvested and evaluate the new stand's potential for hardwood production. Conversely, when managing mixedwood areas for softwood production, foresters need to estimate aspen competition as an obstacle to conifer establishment. Such prediction relationships have to be based on local and regional data on the composition and density of aspen in the parent stand, site relationship and so on. In Minnesota, Perala (1977, 1983) found that 120 parent stems per ha are needed to produce fully stocked stands, and 40 parent stems per ha are needed for minimum stocking of 60 percent. Doucet (1979, 1989) suggests that in Quebec, full aspen stocking can be achieved with a basal area of 5 m^2/ha in the parent stand as long as the aspen stems are no more than 8 to 10 m apart.

In northern Alberta, Forestry Canada in Edmonton, has initiated a study to quantify aspen regeneration and ingress of sucker and seed origin on cutblocks following harvest of pine-aspen and pine cover types. Data from field surveys document areas restocked by suckers from a single aspen tree (Fig. 2) and density of seed origin aspen by site type (Fig. 3). Work is in progress to develop a silviculture decision model for predicting aspen regeneration to facilitate ranking areas for hardwood and softwood production and silvicultural treatments.

Regional surveys indicate that despite the strong interest and efforts to grow and manage conifers, most sites end up with mixed regeneration because of aspen encroachment either by suckering or seeding-in. In addition to the concerns about a potential gradual shift from the boreal mixedwoods to boreal hardwoods (McDougall 1988, Rowe 1989, Peterson et al. 1989) there are lingering uncertainties about the future development of mixed regeneration and its long-term effects on softwood and hardwood AAC. Our forecasting abilities on stand development of mixed regeneration and on interactive growth of aspen and conifers in the mixture are very poor. It is essential to obtain such information with suitable linkages to long-term wood supply projections.

STAND DENSITY MANAGEMENT AND STAND PRODUCTIVITY

As mentioned before, aspen cutovers generally produce very dense regeneration. Although the amount of logging slash on the ground and season of logging results in substantial differences in initial sucker density, these differences in density largely disappear by 5 to 10 years of age (Bella 1986). This means that more young trees die when growing under dense conditions than growing in open stands; and this trend seems to continue at least during the early stand development stage.

This self-thinning tendency of aspen stands has important implications regarding stand tending. Unlike some intolerant pine species, aspen even at high initial densities will maintain the usual rapid height growth and reasonable diameter growth and will produce maximum total wood volume (Bickerstaff 1946, Jarvis 1968, Schlaegel 1972). However, reducing excessive density at a young age by thinning can substantially accelerate diameter increment of crop trees, enhance the earlier production of usable

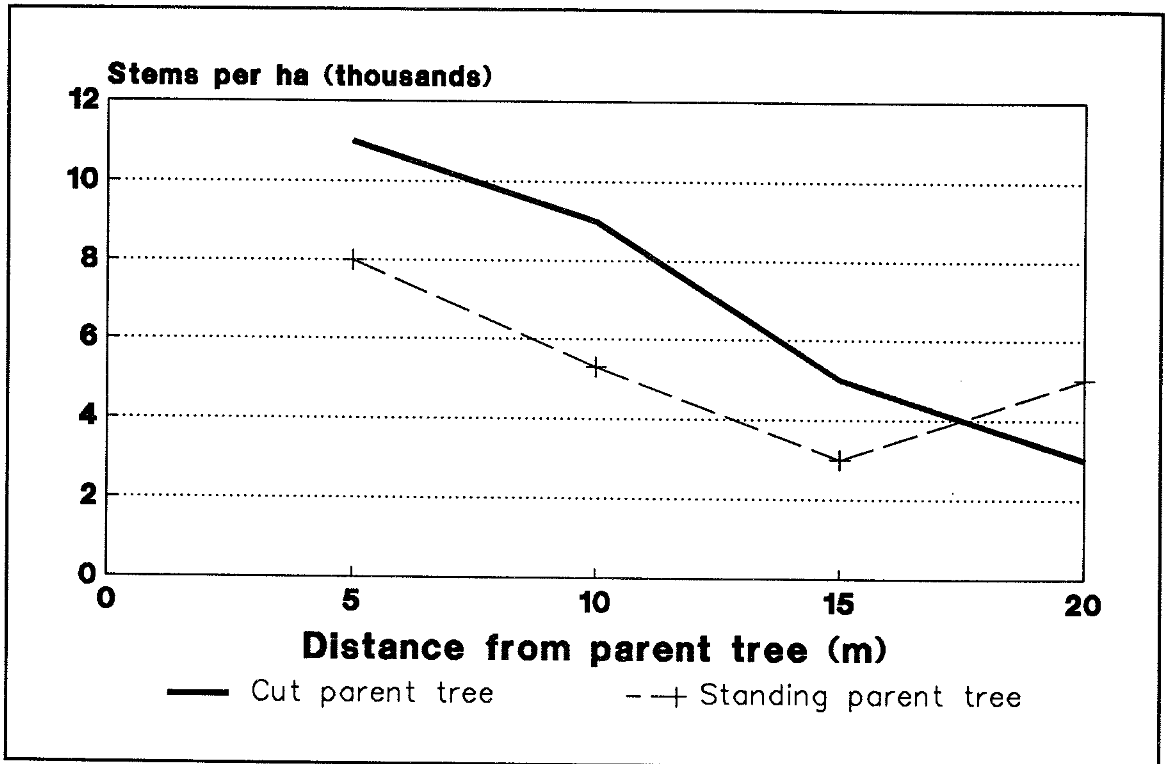

Figure 2.--The density of aspen suckers in relation to distance to the parent tree at 11 to 13 years after harvest from Grande Prairie region, Alberta.

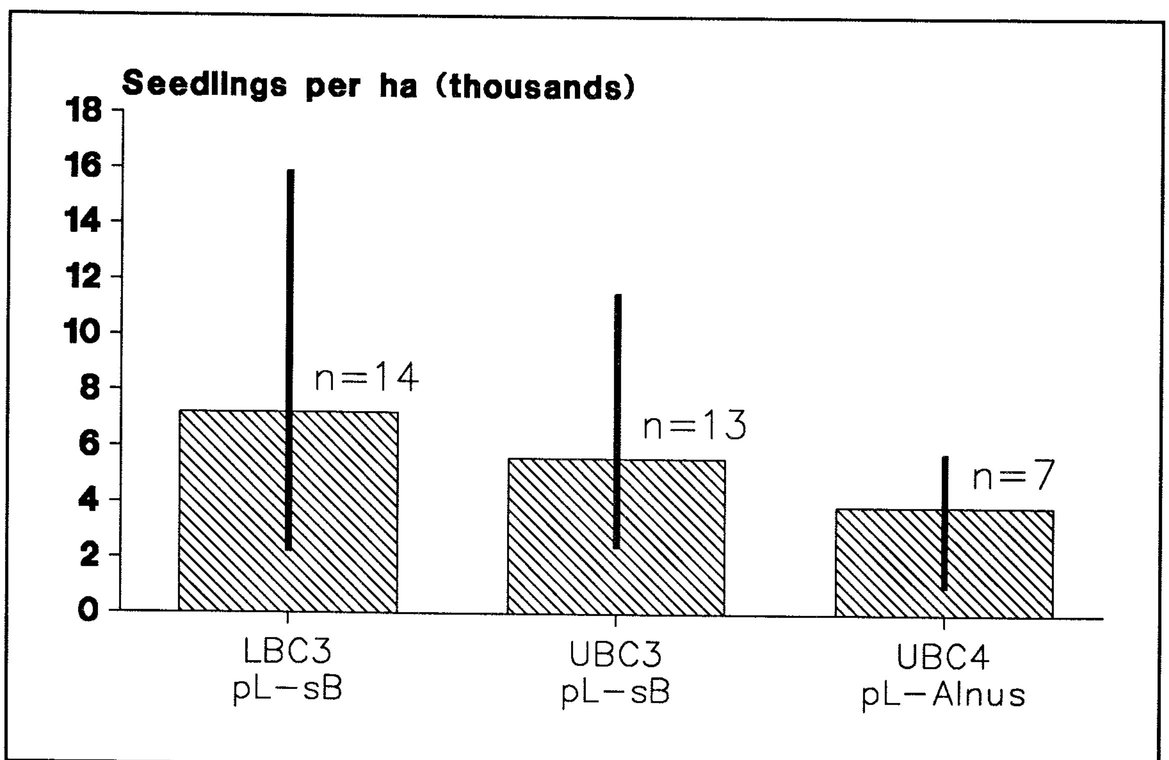

Figure 3.--Aspen density of seed origin in cutblocks at 7 to 20 years after harvest in pine cover types, bars indicate the ranges. Ecosystem associations after Corns and Annas (1986).

material (Bickerstaff 1946, Schlaegel 1972, Perala 1978) and thus reduce rotation length. As decay losses rapidly increase with age, shorter rotation will tend to reduce such losses.

Although thinning may thus somewhat enhance the production of larger, sawlog size material, the production of total stem volume, or merchantable volume to close utilization standards (e.g., pulpwood or similar size timber) is generally adversely affected by thinning (Bickerstaff 1946, Jarvis 1968, Mowrer 1987). This is also well illustrated by the latest growth data at age 59, from one of our aspen thinning experiments from west-central Manitoba established 36 years ago on relatively good growing sites. These experiments also show the greatest total stem volume production in unthinned stands, and declining production with increasing thinning intensity (Fig. 4).

Tree growth characteristics and associated stem quality, as well as insect and disease resistance generally have a strong genetic component and thus provide an opportunity to improve stand quality through judicious tending practices. Undesirable clones, whether because of poor growth habits or disease susceptibility, can be identified and removed. This "sanitary thinning" may be feasible in aspen stands where trees of different clones are intermixed rather than grouped (Navratil 1987).

In planning any silvicultural activity including stand density control treatments, the chief consideration is the most effective production of usable wood for harvest. At present the prime use for aspen timber in Western Canada is oriented strandboard (OSB) and pulp manufacture; and there is no reason to expect any major shift in utilization.

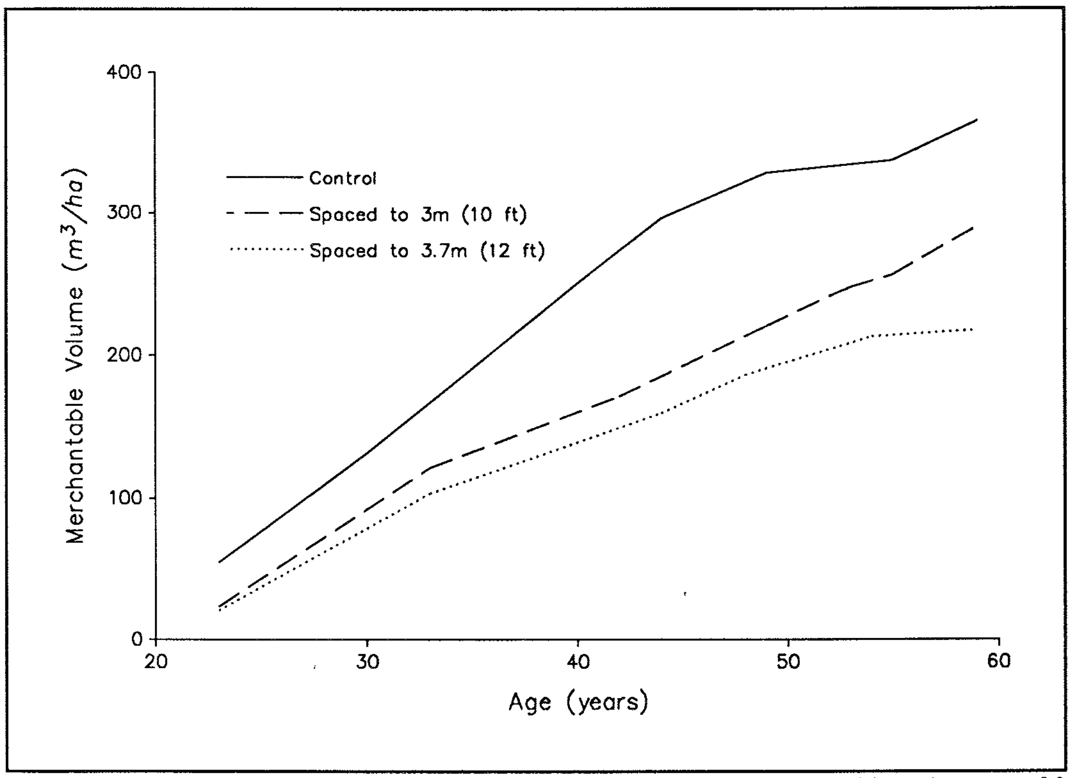

Figure 4.--Merchantable volume of aspen at three density levels. Thinned at age 23 to 3 and 3.7 meter spacing and untreated control. Merchantable volume: stump height - 15 cm and top dib - 8 cm.

Thinning young aspen stands does not enhance pulp- or OSB-wood production; if anything, it has the opposite effect. If one also incurs considerable treatment costs -- at present at least $300/ha in Western Canada -- to be carried to the end of the rotation, thinning clearly becomes an unviable option.

Another important consideration in thinning aspen is this species' susceptibility to stem infections and decay from even minor thinning injuries. Thin bark and the lack of a strong protective response, are the main reasons. Decay from wounds can spread quickly and usually means the loss of the most valuable part of the stem.

A related problem is what appears to be an increased incidence of Hypoxylon canker in heavily thinned stands, as noted by Anderson and Anderson (1968) and others, and covered in this symposium by Ostry and Anderson. We also observed the increased incidence of cankers and top damage in two aspen thinning trials -- 35 and 59 year old stands-- in the Porcupine Mountains of west-central Manitoba and east-central Saskatchewan.

Another problem that can arise in thinned aspen stands is sucker initiation and establishment of shrub and herb layers induced by canopy opening and inherently loose open crowns. Although understory aspen suckers generally succumb, the shrub layer may persist and thrive, especially as the stand ages. This creates difficulties in regenerating aspen following harvest.

In some situations, providing forage for grazing domestic livestock is an important consideration, and opening up aspen stands by thinning may be viewed as a possible solution. This is probably an undesirable option as the shallow rooted aspen may suffer both from direct physical damage to roots and soil compaction caused by livestock. On the other hand, thinning aspen might be desirable where amenities such as access and appearance are main considerations, e.g., in campgrounds and parks, and in stands adjacent to roads and trails used for recreation. Thinned stands have a neat appearance and are generally more suitable to various recreation pursuits at an earlier age than unthinned stands. The cost of treatment is also easier to justify for such uses.

GROWTH AND YIELD PREDICTIONS

Procedures described here are those used in the four western provinces to update forest inventories and to project growth and yield of stands to rotation age for AAC calculations. All these procedures are based on information from old growth, natural untreated stands and should be suitable for aspen in most cases with the possible exception of east- central Saskatchewan where there are now large areas of second growth aspen stands that originated after harvesting old growth for flake-board manufacture. The interim modelling assumption for growth and yield prediction in these stands is that they will produce at least the same yield at rotation as former old growth stands.

In British Columbia, Variable Density Yield Tables have been developed by the Forest Service (BCMOF 1983) for all commercial species growing in pure stands. A lack of crown closure estimates for all polygons in the inventory, however, has prevented their implementation. Until 1989, an interim system was applied to update inventory statistics and calculate AAC. The system utilizes temporary (inventory) and permanent sample plot data fitted to a non-linear yield model -- a reformulation of the Chapman-Richards function following Ek (1971)-- with age and site index as independent variables.

Volumes to different merchantability/utilization levels are estimated using volume ratios derived from a hyperbolic function using the same independent variables. As crown closure information is now available in the forest inventory throughout the province, a revised growth and yield prediction system based on the variable density approach using connected permanent growth plot data is being developed for implementation in 1990 (pers. comm. J. E. Vivian, June 1989).

In Alberta, the Forest Service uses empirical yield growth curves for the major cover types developed for each Volume Sampling Region (VSR) (Alberta Forest Service 1985) to update inventories and project yield of stands to rotation age. Each VSR represents a group of townships with similar biogeoclimatic characteristics and 11 of these cover the province's forested areas. The yield curves represent average fully stocked stands, i.e., C and D density classes. In using these yield curves, no allowance is made for the understocked stands to approach fully stocked conditions, so yields tend to be underestimated. Work is in progress to develop a new system of yield forecasting that would account for the "trend towards normality".

In Saskatchewan, where conditions are fairly uniform in the commercial aspen zone, mature and overmature aspen volumes are determined directly from the forest inventory data, and immature stands are "grown" using a fixed yield value derived from present mature stands. This fixed yield is also used to determine Long Run Sustained Yield, which is assumed to be the best estimate of the second rotation harvest levels (pers. comm. D. Dye, 1989).

Manitoba uses a similar approach. Mean annual increment values are obtained from the forest inventory, then they are used in conjunction with stand tables, volume tables, and area summaries to calculate annual allowable cut. They are enhancing their inventory as budgets permit, and will be moving towards improvements in yield forecasting, be it traditional variable density yield tables developed for the purpose, or locally calibrated versions of complex simulation models (pers. comm. G. Peterson, 1989).

In the regional scene, the Northern Forestry Centre in Edmonton conducts research and development in Alberta, Saskatchewan, Manitoba, and the Northwest Territories, and has been active in aspen growth and yield work over the last thirty years. Several thinning experiments have been established and monitored over the years and the results published. Temporary sample plot yield data for aspen were also collected and preliminary yield tables constructed for Alberta and Manitoba; while in Saskatchewan the provincial forest service developed and published yields tables for this cover type (Kirby et.al. 1957). Recently some of our long term aspen growth data were used to test STEMS (Stand and Tree Evaluation and Modelling System, e.g., Miner and Walter 1984) in the region for natural fire origin, untreated stands and for thinned stands. For both conditions the model gave reasonable predictions.

CHALLENGES IN ASPEN MANAGEMENT AND SILVICULTURE

Not surprisingly, increasing interest in the aspen resource in western Canada is revealing new challenges in its management and silviculture. These challenges have been grouped under ten key subjects as follows. The term 'hardwoods' is used to refer to both aspen and balsam poplar, but here it pertains mainly to aspen because that is the dominant hardwood species in western Canada.

LAND USE ALLOCATIONS FOR HARDWOOD AND SOFTWOOD PRODUCTION

Integration of softwood and hardwood harvests on the same land base by different users needs innovation. Experience to date is limited on how to successfully remove hardwoods from lands allocated to softwood licensees. Techniques to reduce damage to white spruce during hardwood harvesting were suggested by Froning (1980) and reviewed by Johnson (1986). More recently, Brace and Bella (1988) and Brace (1989) discussed harvesting methods to remove aspen while protecting the white spruce understorey.

In western Canada, criteria are not yet well defined to decide when the hardwood or the softwood resource carries priority in circumstances of overlapping tenure. Many realize that there are advantages to an integrated approach to softwood and hardwood harvesting from the same land base, such as reduced harvesting costs and better protection of the site, and improved regeneration as a result of better planning and operational control. It is also good public relations to demonstrate higher levels of utilization. In addition, market fluctuations for coniferous products can be dampened by markets for hardwood products (Denney 1988).

A whole new set of regulations and policies, harvesting and regeneration technologies, and ethics on the use of the existing stands and the regeneration of future forests on mixedwood cover types must evolve (Murphy 1988, Beck et al. 1989).

NEED FOR IMPROVED INVENTORY OF THE HARDWOOD RESOURCE

Recently, a committee in the British Columbia Ministry of Forests (BCMOF), which defined twelve current problems related to hardwood management, identified improved hardwood inventory and data on the relative proportions of hardwoods and softwoods in many mixedwood stands as the highest priority need (Revel et al. 1986). Furthermore, across the Mixedwood Section in western Canada, a need exists for better data on size and age class distribution of softwood regeneration beneath aspen overstories.

Earlier inventories often underestimated the balsam poplar component in aspen-balsam poplar stands. Recently, Minnesota and Alberta have been involved in a cooperative exchange of ideas on how to achieve better aerial photography for identification of hardwood species for inventory purposes (Westfield 1987).

The proper aging of hardwood stands remains a difficult problem, particularly in mature stands that have well advanced stem decay. In Alberta, recent re- aging of aspen with field laboratory equipment revealed that many stands originally classified as 120 years of age are only 80 years old, 80 year stands are only 60, and 60 year stands are only 50. For stands 40 years or younger, previous aging has been relatively accurate.

HARDWOOD DECAY - UTILIZATION RELATIONSHIPS

Decay and stain influences on aspen utilization continue to create uncertainty amongst those who produce, manage and use this resource in the west, but it is less of a concern now than it was a decade ago. The major problem remaining is predicting the amount of stain and decay in existing or future hardwood stands. Despite numerous aspen decay studies, the decay estimates in standing trees and prediction of cull remains a problem, partly because of the biological complexity of tree-decay relationships and partly due to incompatibility among the decay studies and inconsistencies among investigators (Basham 1987, Navratil 1987, Hiratsuka and Loman 1984). There are strong economic incentives for more accurate estimates of cull in aspen and balsam poplar and several studies are in progress. The Alberta Forest Service is searching for criteria that would aid identification of rot-free aspen stands and Forestry Canada, Northern Forest Centre is completing a field guide for aspen decay and stain identification (pers. comm. Y. Hiratsuka, 1989).

Some of the present anxiety about aspen use is based on a belief that much of the present volume will not be available because of rapid losses from stand break up, in addition to cull from decay, after 80 years of age (Dempster 1987). Realistic projections of aspen break up are one of the main requirements for more accurate determinations of AAC.

Aspen decay management will require policies different than those developed for softwoods, which in Alberta has been to schedule harvests first in the oldest and least healthy stands. The present forest inventory indicates that many Alberta aspen stands are too old or too young to use. As a result there is actually a relatively narrow range of age classes in which the trees are of suitable size and still without severe decay. Aspen management involves difficult decisions that are often influenced by the marketplace. Just as aspen managers cannot ignore the realities of aspen age-class distributions, neither can they ignore the effect of wood quality criteria upon the marketability of many products. The latter point is well documented by Kennedy (1974) and Wengert (1976).

QUALITY OF SECOND-GROWTH STANDS

Aspen stand quality following harvesting has not been documented in western Canada. In the absence of site specific studies within the region, one may assume that observations on pathological quality of aspen suckers from northern Ontario are applicable (Basham and Navratil 1975, Kemperman et al. 1976, Weingartner and Doucet in this Proceedings). Kemperman et al. (1976) concluded that the development of second growth aspen stands will probably not be seriously limited by defect until they are at least 40 - 60 years of age.

In view of frequent use of mechanical site preparation on mixedwood sites, root rot and stain defects, especially by Armillaria spp., are likely to be more common and more important in newly regenerated stands. Basham (1982, 1988) reported the increased stem and root defects in aspen suckers after heavy drag scarification.

There is very little literature on the influence of insects on young aspen stands. Webb (1967) indicated that in heavily stocked aspen stands the death of a number of the trees, particularly the suppressed and intermediate individuals most vulnerable to borer and fungi attack, will improve the health of residual trees.

There has been some concern that post-harvest sucker stands may be falling behind in desired stocking and distribution, particularly on mixedwood sites. Insect and disease infestations could have greater impact in future managed stands with lower sucker densities than in fire origin stands. In addition, productivity of these stands could be reduced due to lower stocking and density alone, and in combination with the pest impact.

REHABILITATION OF HIGH-GRADED AND OVERMATURE STANDS

There are aspen stands in western Canada where most remaining trees are decadent because of previous high-grading. This is most prevalent where aspen has been harvested for plywood. For example, near Hudson Bay, Saskatchewan, many stands may now be beyond any utilization potential. About 182,000 ha of mixedwood and 265,000 ha of pure aspen stands in Saskatchewan have reached such an overmature and decadent stage (pers. comm. A. Kabzems, 1988).

Uneven-aged stands can develop from other causes as well. The break-up of mature stands is one of these. Aspen stands that have escaped fire for 90 or more years may have an advanced understory of aspen, often in the range of 40 to 50 years, and there may also be even younger aspens in the shrub layer. The dynamics of these stands are poorly understood. Experience indicates that multi-aged aspen stands are the most difficult management challenge. The most direct remedy is conversion to single-aged stands. The challenges are to select the best silvicultural options to re-establish a new vigorous aspen stand and to select the "best" sites to do this. The criteria developed for the poplar working group in Ontario (Davison et al. 1988), and methods used for stand regeneration in Minnesota (Perala 1983, Jones 1987) may be applicable to western Canada.

It is more difficult to decide which are the "best" sites for aspen renewal. Because aspen prefers the same sites as the more valuable softwood species (Corns 1988, 1989), there is a dilemma about whether hardwoods or softwoods should be favored. Although aspen can occur as a dominant or codominant on a wide range of sites, Corns (1988) suggested that the choice between white spruce or aspen should consider the relative productivity potential of each species, rather than which species currently occupies the site.

High-grading as a cause of uneven-aged stands is not expected to be a problem in the future. Technological changes and greater utilization of the aspen resource encourage the use of all grade and site classes. Similarly, the overmaturity problem will disappear as mature and overmature stands are gradually harvested and renewed or rehabilitated. There are strong economic and silvicultural reasons to rehabilitate the current large areas of decadent stands and bring them back to full production. A task of this magnitude will have to be supported by appropriate management regulations and incentives, which are currently lacking.

MANAGEMENT OF BALSAM POPLAR COMPONENT

In many aspen stands in western Canada, as much as one-third of the basal area identified as aspen is actually balsam poplar (Fig. 5). Due to the low demand, most of the balsam poplar is left standing in aspen cutovers. These residuals have a negative influence on aspen suckering, and also hinder site preparation. This problem will diminish as balsam poplar will be increasingly accepted by the forest industry. For example, two newly announced pulp mills in Alberta will be using both aspen and balsam poplar.

With increased utilization of balsam poplar, several other questions arise about its regeneration silviculture, treatments for its encouragement, and density and stocking requirements for optimal growth. We do not know what growth and yield we can expect in second growth balsam poplar, or in mixed stands of balsam poplar and aspen.

Little is known also about wildlife implications of balsam poplar utilization. As a wildlife browse species, aspen is superior to balsam poplar. For this reason it is important to know if current or future practices of aspen-balsam poplar harvest will lead to a long term increase in balsam poplar. Furthermore, long-lasting balsam poplar residuals provide important habitat for cavity-nesting birds.

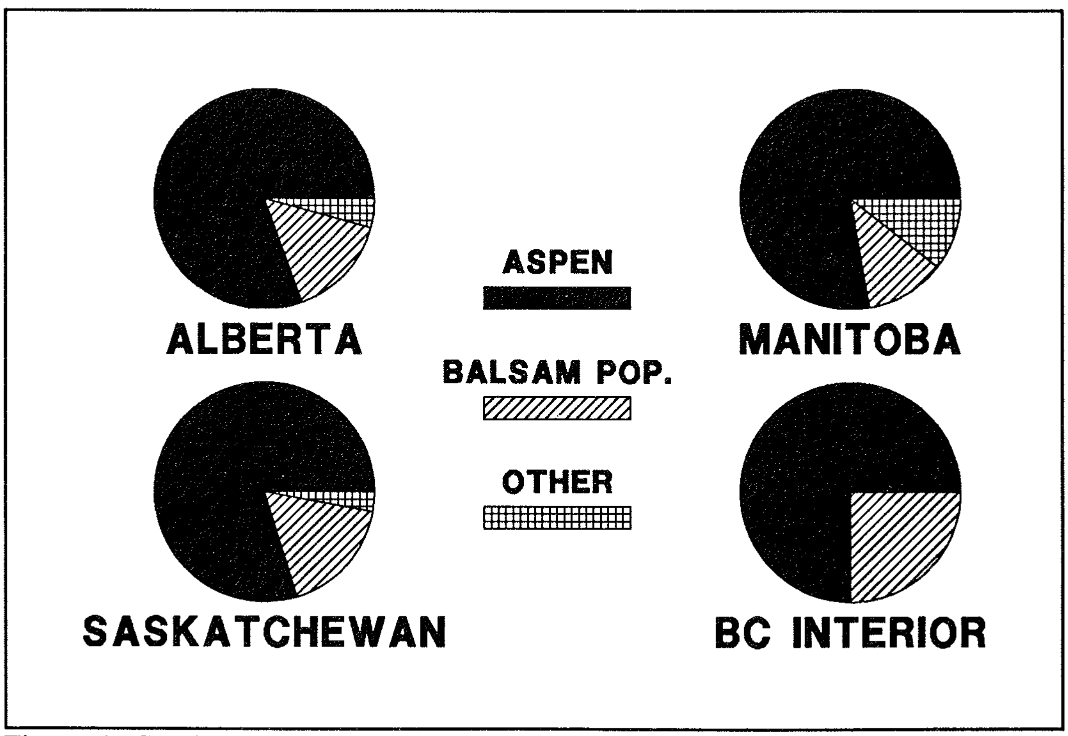

Figure 5.--Species mix in aspen (hardwood) stands in western Canada.

WILDLIFE IMPLICATIONS OF CHANGING HARDWOOD MANAGEMENT

Wildlife concerns on forest land figured prominently in the 1989 survey of Canadian public opinion on forestry issues (Environics Research Group Limited 1989). It showed that 35 percent of the respondents identified environment/wildlife as the greatest concern, 27 percent of those surveyed identified wildlife as the most important use of Canada's forests and logging (timber value) came in fourth. Publicly expressed concerns about the wildlife implications of increased hardwood harvesting in western Canada usually focus on reduction of habitat diversity and a trend towards an increased hardwood component in the mixedwood region.

D.A. Westworth and Associates Ltd. (1984) examined the potential effects of short-rotation harvesting of boreal aspen stands on wildlife in Alberta. The study involved a comparative evaluation of habitat conditions and wildlife use of aspen stands of different ages; including 1 and 2-year-old clearcuts, and 14-, 30-, 60-, and 80-year-old stands. Overall densities of breeding birds were predicted to increase under short-rotation management, however approximately one-third of the species common to aspen forests would undergo a significant decrease in abundance. The absence of large diameter snags in managed stands would result in a pronounced decrease in abundance of snag- dependent birds. Browse production was highest in the 14-year-old stands, while maximum production of grasses and forbs occurred in the 14- and 30-year- old stands, respectively. As a result, short-rotation harvesting would be beneficial to ungulates as long as management programs include silvicultural options designed to meet the cover requirements of each species. Among the furbearing mammals, snowshoe hares, beaver, lynx, coyotes and wolves would likely benefit while species such as marten, fisher and red squirrel would be adversely affected by a reduction of mixedwood or coniferous forest under short-rotation management.

Sizes and patterns of cutovers have long been of concern to wildlife officials. In Saskatchewan, softwood clear-cut areas are currently limited to 40 ha and hardwood clearcuts range from 120 to 400 ha (Little 1988). In their suggested methods for reclamation of moose habitat in the prairie provinces, Green and Salter (1987) recommended the maintenance of dense forest blocks at least 1 ha in size to provide escape and thermal cover within clearcut areas. Recommendations on size and distribution of habitat units are provided by Green and Salter (1987) for all of the large mammals that inhabit mixedwood and aspen parkland areas in Alberta, as well as for spruce grouse, and sharp- tailed grouse.

PUBLIC CONCERNS ABOUT CHANGING HARDWOOD MANAGEMENT

The 1989 National Survey of Canadian Public Opinion on Forestry Issues (Environics Research Group Limited 1989), commissioned by Forestry Canada, confirmed that a substantial majority of the 2,500 Canadians polled are concerned about forest management in Canada. In western Canada, that anxiety impinges directly on use and management of the aspen resource, judging from the concerns most commonly voiced: dislike for large clear-cut areas; doubts about the effectiveness of forest renewal programs; and fears that future forests will resemble agricultural monocultures. In the prairie provinces, 69 percent of respondents disapproved clear cutting as a logging method. Because there is so little history of hardwood harvesting in western Canada, these concerns are presumably based on public perceptions of coniferous harvesting. The public does not understand that clear cutting is the only effective way to achieve aspen regeneration. Where this is understood, the issue generally centers on the size of clear cuts and disruption of wildlife habitat.

The Canadian public is familiar with nursery production of seedlings and with planting because this method of coniferous forest renewal has been well publicized in recent years. The effectiveness of root sucker regeneration in aspen is not as well known to the public. Foresters are being asked why nurseries are not now gearing up for production of deciduous planting stock, in view of the large amount of hardwood harvesting on the horizon. This question suggests that there is a need for public information programs and demonstration areas to publicize that aspen sucker regeneration makes nursery production and subsequent planting of seedlings unnecessary.

ASPEN RESOURCE AND INDUSTRIAL DEVELOPMENTS

The aspen resource in western Canada has been called a "huge and hidden resource." Over the past 20 years several meetings and symposia were held with the objective to promote aspen utilization in the region. These did not result in a significant upsurge in aspen use until recently, when technological improvements (e.g., in OSB, CTMP manufacture) together with increased demand for forest products and economic strength in the forestry sector resulted in major breakthroughs in aspen utilization. As one Alberta government manager implied, the current expansion of the industry and the dramatic increase in hardwood use in Alberta resulted from favorable economic circumstances as well as from aggressive industry development and promotion programs guided by the provincial government (Brennan 1988).

Alberta has been the major focus for forestry developments in Canada and the province is experiencing a total of 3.4 billion in new capital investments. Expanded pulp production for 1988 to 1991, and the list of new and announced pulp mills illustrates this point (Table 1). Most of these new developments will use aspen, some up to 80 percent of the total consumption.

Aspen consumption planned for the new mills represent a giant step in aspen use in western Canada. The wide gap between aspen AAC and harvest that existed even 2 - 3 years ago is narrowing very quickly in some areas (Fig. 6), especially when one considers economically accessible timber. The increasing trend in aspen utilization will likely continue, with occasional declines related to market conditions, alternate land use demands, and environmental considerations.

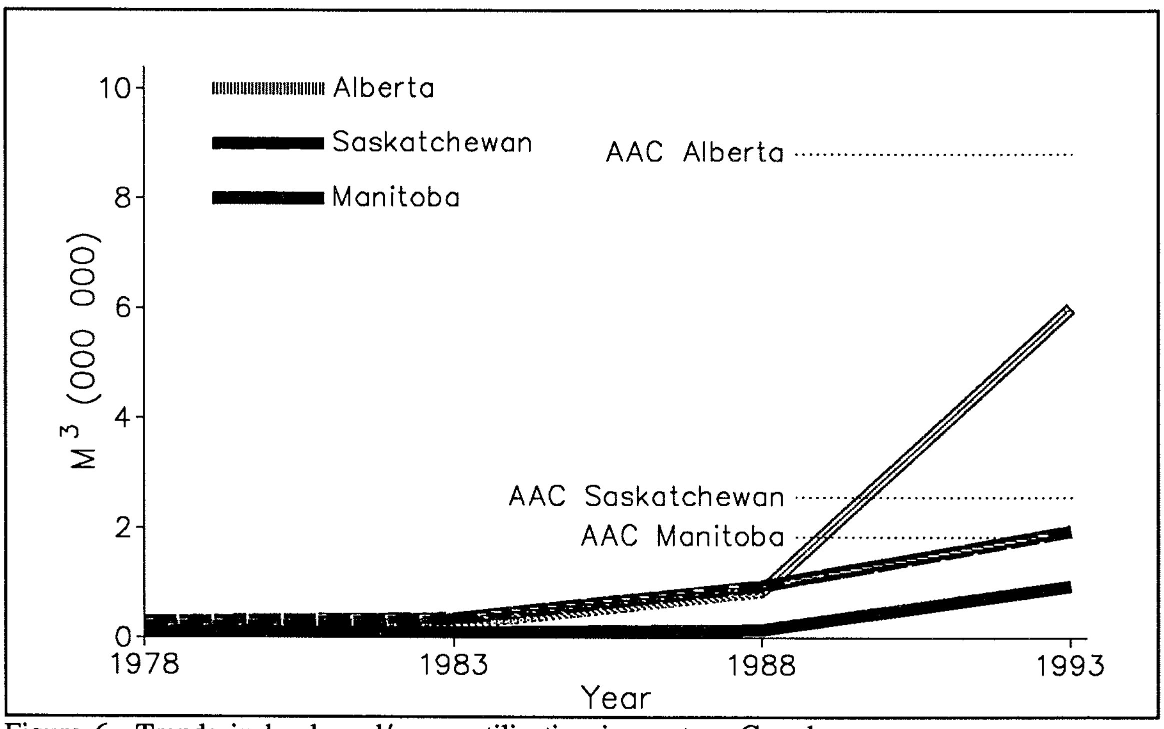

Figure 6.--Trends in hardwood/aspen utilization in western Canada.

Table 1.-- New and proposed aspen pulp and paper mills in Alberta.

Company	Location	Process	Start of Operations	Utilization Aspen (million m³)	Utilization Softwood (million m³)
Millar Western Industries Ltd.	Whitecourt	CTMP	1988	0.31	0.30
Daishowa Canada Co. Ltd.	Peace River	BKP	1990	1.19	0.63
Alberta Energy Co. Ltd.	Slave Lake	CTMP	1991	0.26	0.05
Alberta-Pacific Forest Industries Inc.	Athabasca	BKP	1991	1.80[1]	0.36
Procter and Gamble Cellulose Ltd. (Expansion)	Grande Prairie	BKP	1992	0.69	0.69
Alberta Newsprint Company Ltd.	Whitecourt	Newsprint Mill	1990		

[1]Includes balsam poplar.

Source: Alberta Forestry, Lands, and Wildlife; W. Ondro, Forestry Canada

IMPROVEMENTS IN ASPEN REGENERATION AND SILVICULTURE

New approaches to aspen as a commercial crop and longer planning horizons in management and industrial strategies have quickly changed the approach to and appreciation of aspen silviculture and management. A survey on aspen management prospects conducted in the region revealed a strong consensus amongst respondents that aspen regeneration and growth are important concerns today and require appropriate management action. Many respondents are ready to consider intensive silviculture practices to improve the health and productivity of the aspen resource where required. Although aspen regeneration is generally assured after clearcutting of hardwood stands, there are situations where regeneration investments may be needed.

Soil compaction may cause understocking on sensitive sites (moist, heavy soils) and so can shrub and grass competition, which may also hinder the growth of regeneration. Modification of harvesting technologies and careful planning of the season of harvest can provide solutions. In addition, new harvesting technology will need to be developed that will allow aspen removal, while protecting the advanced conifer regeneration in two storey stands.

Although more remote, planting of improved aspen and poplar stock on abandoned farm land near manufacturing facilities by forestry enterprises may become feasible in the future. These would be intensively managed plantations grown in short rotations. While spacing and thinning programs will not increase the production of wood for pulp or OSB, they may be applied in areas where unbalanced age-class distribution requires augmentation of merchantable yield at certain periods.

THE GREENHOUSE EFFECT AND ASPEN MANAGEMENT

Any projections of aspen growth, management, and utilization are based on the premise that the natural environment will remain the same. Should a major change occur in the climate, the conditions for growth and survival will change. Climatologists are concerned that the steady increase of "greenhouse" gases, such as carbon dioxide and methane, in the atmosphere will result in an unprecedented rapid rise in temperature. It is anticipated that the global temperature will rise up to 5°C by 2050, and that the increase will be pronounced in the northern hemisphere (Manabe and Wetherald 1986). Precipitation would remain the same, or increase slightly in the western interior of Canada.

It is expected that this change will be manifested by longer growing seasons and warmer winters, with a slight rise in the summer temperatures. The higher temperatures will induce greater evapotranspiration, resulting in higher water consumption by plants. Moisture deficiency will occur with increased frequency and longer duration, especially in the southern part of the boreal forest. Severe drought and subsequent diseases, such as Hypoxylon and Cytospora cankers, can kill aspen stems while the roots remain alive and sucker growth will follow. However, repeated droughts may exhaust the trees, finally killing them. This would result in a generally northward expansion of the grasslands and aspen parklands, well into the present boreal forest by the mid 21st century.

The effect of the change in the climate would be a northward expansion of the present vegetation zones. Aspen would suffer severely in the south, but would benefit in the north (Fig. 7) from the longer growing season and milder winters. Aspen is expected to flourish in northeastern British Columbia, and in northern Alberta, but the stony, shallow soils of the Canadian Shield will limit its growth in northern Saskatchewan and Manitoba. Aspen may spread to higher elevations in the foothills, where it should do very well.

Changes in aspen growth can be expected at any geographic location. Aspen- using industry, located in the south, may find local supplies dwindling and transportation costs increasing necessitating a move north. Regeneration is likely to fail in climatically stressed areas.

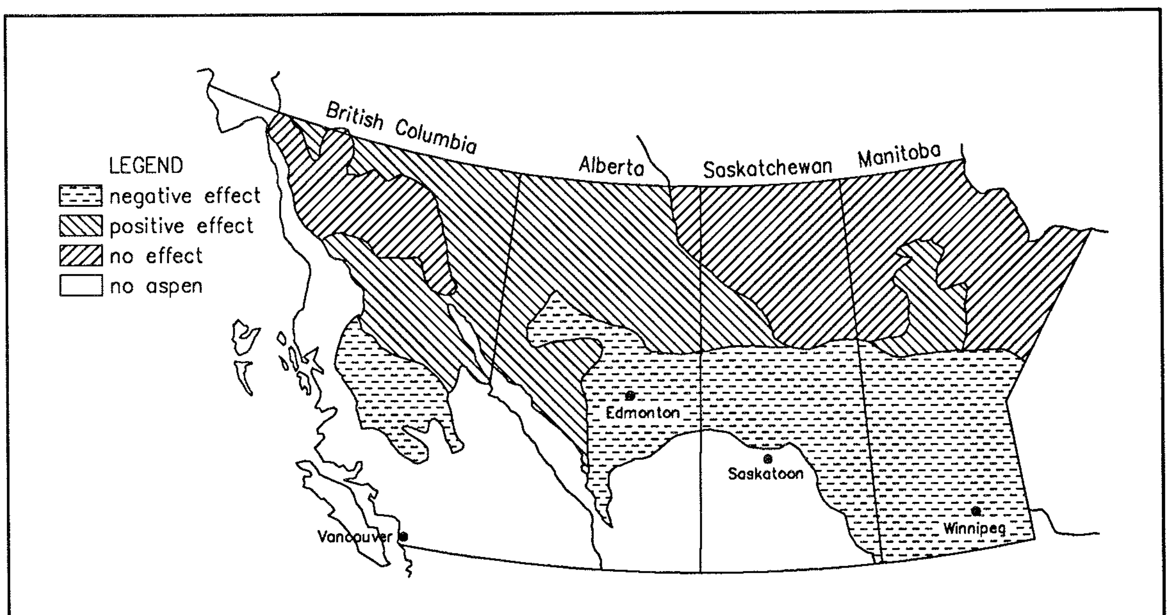

Figure 7.--Anticipated effects of 2 x CO_2 warming on aspen. Some areas are mapped as "no effect" because of unfavorable edaphic or physiographic conditions. (Provided by S. Z. Zoltai, Forestry Canada, Edmonton).

FUTURE ASPEN RESOURCE

One may wonder whether the current upsurge in aspen utilization might run out of steam, or simply run out of aspen, as we have run out of eastern white pine and are close to running out of white spruce. Although it is possible to degrade the aspen resource, e.g., by reducing genetic diversity, it is unlikely that this resource in western Canada could disappear even after several rotations. Aspen is a permanent member of the Boreal Forest community, and neither fire nor logging can eliminate it. Its vigorous suckering and seeding ability ensures its continued presence and growth in this region. Aspen is a resilient species that occupies a broad range of sites (Corns 1988). This ecological resiliency bodes well for aspen. Not only will aspen persist, but further increases in aspen AAC can be expected, or enhanced when needed, from several sources. Aspen harvesting is now concentrated in stands of old age classes. A shift to younger stands will result in shorter rotations, which will also mean a simultaneous reduction in cull and more complete utilization.

A good portion of the aspen growing stock is in agriculture fringe areas, dispersed among many small holdings. Demand for aspen wood will open a significant supply source from those "woodlots", and thus widely benefit the local economy. At least one of the newly announced forestry developments in Alberta will procure a significant portion of its aspen log supply from private woodlots. Additional fibre sources will be generated from closer utilization of aspen wood by satellite chipping, whole tree harvesting, and technological improvements in pulping and OSB manufacturing.

A significant increase in the hardwood growing stock is occurring over extensive areas of the Boreal Mixedwood section because of the steadily increasing aspen component in mixedwood and conifer cover types. In the long run, this will mean a significant shift of the conifer land base towards hardwoods, although appropriate management policies are not yet in place to reflect this situation. So reassessment and realignment of forest management strategies are urgently needed.

Commercial interest in aspen is expected to be as enduring as the species itself. Aspen's prime use - pulp and panelboard - are likely to endure in world markets. Aspen has also been described as the "true champion" of multiple use (Thorp 1988) and is also highly regarded in terms of aesthetics and public perceptions.

Aspen utilization has made a giant step in the west. The work has just begun. It is now up to researchers, policy makers and forest practitioners, to respond to this momentum and develop sound forest management and renewal strategies to sustain our aspen forest.

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THE QUEST FOR ASPEN MANAGEMENT IN EASTERN CANADA

David H. Weingartner and René Doucet[1]

ABSTRACT.--In eastern Canada aspen represents 0.03 percent to nearly 20 percent of the individual provincial growing stock volumes. Regional and local differences in growing stock volume and markets influence the management view of the resource. A significant portion of the resource is located in Ontario and Quebec, and is in mature to over mature stands that may contain high levels of defect. Previous silvicultural efforts were directed at eliminating aspen in favor of softwoods. However, expanding markets and changing technologies are provoking serious thought about how to manage this resource. Precommercial and commercial thinning of aspen in pure and mixedwood stands may be key treatments in managing this increasingly important resource.

THE RESOURCE

Eastern Canada stretches approximately 3000 kilometers from the Manitoba-Ontario border to eastern tip of Newfoundland. Over such a broad expanse there are significant regional differences in forest ownership patterns, forest cover types, and the quantity and quality of the available aspen resource. Trembling aspen (Populus tremuloides Michx.) and largetooth aspen (P. grandidentata Michx.) both occur in eastern Canada, although trembling aspen is generally the most common. The total poplar growing stock volume in eastern Canada is approximately 1.3 billion cubic meters.

In Atlantic Canada, market opportunities for aspen are restricted either due to the limited quantities available or the lack of industry that uses aspen as a feedstock. The greatest portion of the poplar resource, in eastern Canada, is located in the provinces of Ontario and Quebec where market opportunities are better due to the size and diversity of the forest industry and the quantities of aspen available (Table 1).

NEWFOUNDLAND

Aspen is present on most of the island of Newfoundland, but it forms stands only in the north-central part of the province. These stands develop after fire (Damman 1983). Cull and decay are lower than in aspen of the same age situated elsewhere, and mean merchantable volume increment culminates at age 95 years (Page 1972). Aspen is much more productive than birch or any softwood species, but an increase of the acreage in aspen is needed before commercial utilization is feasible (Page 1972). Large stems may be used when encountered in normal softwood operations (e.g., for bridge building), but there is no industry using aspen commercially at present.[2]

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Table 1.--Aspen growing stock volume in eastern Canada by province.[1]

Province	Volume (m^3)	Percent of Provincial Growing Stock
New Brunswick	41,570,000	7.3
Newfoundland	3,000,000	0.03
Nova Scotia	7,400,000	3.0
Ontario[2]	1,011,200,056	19.8
Prince Edward Island	1,580,000	6.1
Quebec[2]	291,852,000	7.0

[1]Derived from Canadian Forestry Service (CFS) 1987a, 1987b, 1988a, and 1988b, Ontario Ministry of Natural Resources (OMNR) 1986a, and Parent 1987.
[2]Total of all Populus species.

NEW BRUNSWICK

Aspen represents 32 percent of the hardwood sustained yield and has a estimated gross total annual allowable cut (AAC) of 1,191,500 m^3, over half of which is on freehold land, and an estimated net AAC of 834,100 m^3, assuming 30 percent cull (Neill and Gunter Ltd. 1985). Utilization of the poplar resource is limited to one panelboard plant, less than 20 percent in pulp furnish, and practically none in sawlogs (Neill and Gunter Ltd. 1985). The aspen resource by grades is 36 percent sawlogs and 64 percent fiber (McFarlane 1982).

NOVA SCOTIA

Aspen is present primarily in the western and central parts of the province, and is divided into the following products or classes sawlogs 20 percent, bolt wood 17 percent, top wood 12 percent, pulpwood 50 percent, and cull 2 percent (Wellings 1982). Seventy-one percent of the forest land is in private ownership with more than two-thirds being in holdings of less than 400 ha (Wellings 1982).

PRINCE EDWARD ISLAND

While the aspen growing stock volume is too small to support an industry, nearly one-third of a million cubic meters of aspen and other species were used as fuel wood during the 1986 heating season. This represented 12.4 percent of the total energy consumed for heating resulting in a saving of 58.7 million liters of fuel oil (CFS 1987b). Private ownership accounts for 95 percent of the productive forest land (CFS 1987b).

QUEBEC

The annual allowable cut is estimated at 4.8 million m^3, half of which is on private land and represents less than 20 percent of the productive forest land area. The annual commitment is 2.9 million m^3, but the volume actually harvested in 1988 was estimated at 2.0 million m^3. This is a dramatic increase over the volume of 867,000 m^3 harvested in 1980 (Rinfret 1987), and projects in the planning stage suggest that the upward trend in utilization will continue. About two-thirds of the harvested volume is used for pulp and waferboard (figures not available separately) and one-third is used for sawlogs and veneer.

Theoretically, there is a considerable surplus of unused aspen. However, a large part is in mixedwood stands where availability depends on concurrent exploitation of other species, or in old stands where cull and decay become important factors. For example, when the allowable cut was calculated for a waferboard plant that went into production in 1988 in the Lac-Saint-Jean area 25 percent of the gross volume was deducted because of decay and other defects. When these factors are considered, the resource is entirely committed in some regions.

As in other areas, aspen is affected by a number of organisms. Nine different cankers have been reported on trembling aspen in Quebec (Laflamme 1982) with Hypoxylon canker being the most prevalent. A general survey of aspen stands (Benoit et al. 1982) showed that an average of 5 percent of all the stems and 4 percent of the merchantable volume were affected. Annual loss through mortality resulting from Hypoxylon canker was estimated at 1.2 million m^3. A more in-depth study of two management units (Archambault 1982) confirmed these figures, but infection was up to 26 percent in some stands.

ONTARIO

Of the eleven Ontario Forest Resources Inventory (FRI) species groupings, poplar is second only to spruce for total growing stock volume and is an aggregate of the two aspen species, balsam poplar (P. balsamifera L.), and eastern cottonwood (P. deltoides Bartr.) (OMNR 1986a). The major concentration of poplar within Ontario, as delineated by Fitzpatrick and Stewart (1968), occurs in the four northern administrative regions of the Ministry of Natural Resources and represents over 90 percent of the poplar resource, mostly trembling aspen which probably accounts for 80 percent or more of the poplar growing stock volume. The southern edge of this major poplar area coincides roughly with the boundary between the Great Lakes--St. Lawrence and the Boreal Forest Regions (Rowe 1972). Largetooth aspen occurs in commercial concentrations in the Great Lakes--St. Lawrence Forest Region in south-eastern Ontario (Davidson et al. 1988). The Crown holds title to most of the productive forest land and most of the aspen resource in Ontario.

During a recent ten year period the poplar harvest more than tripled from 0.793 million cubic meters in 1977 (OMNR 1981) to 2.768 million cubic meters in 1986 (OMNR 1986b). The harvest represents only a small portion of the volume available; however, other factors reduce the amount available for harvest. During the period 1977-1981 annual losses in growth due to forest tent caterpillar amounted to 933,000 m^3 while 155,000 m^3 of lost increment was attributed to other causes, and direct mortality resulting from Hypoxylon canker amounted to 6,184,000 m^3 (Smyth and Campbell 1987). In addition, total defect (stain and decay) can also be a factor in reducing the available volume. The age class distribution of the poplar resource is skewed to the older age classes with approximately 67 percent of the productive poplar land base, representing 75 percent of the poplar volume, in stands that are mature or over-mature (OMNR 1986a). Basham and Morawski (1964) reported high levels of defect in mature and over-mature stands (Table 2).

Table 2.--Stain and decay as a percentage of total merchantable volume in Ontario trembling aspen.[1]

Age Class (yrs)	Stain (%)	Incipient Decay (%)	Advanced Decay (%)	Total Defect (%)
21-40	5.2	2.4	0.2	7.8
41-60	7.0	5.3	1.0	13.3
61-80	8.2	6.5	2.7	17.4
81-100	10.8	8.1	4.8	23.7
101-120	11.4	12.3	8.8	32.5
121-140	17.3	9.3	10.6	37.2
141+	16.3	7.2	18.7	42.2

[1]Modified from Basham and Morawski 1964.

CURRENT PRACTICES

QUEBEC

Until fairly recently, aspen utilization was localized and much of it was for veneer and sawlog production. Large trees were used in some areas, but for the most part aspen stands or trees in mixedwood stands were left standing. Doucet (1989) found that a partial cut resulted in a gradual reduction in the growth of newly produced aspen suckers with a concurrent increase in brush density. He suggested that this would result in the production of an irregularly stocked stand of aspen.

The only general restriction on harvesting is that clearcut size must not exceed 250 ha (Walsh 1989). Special sites may be identified for recreation, wildlife, or conservation purposes. On these sites the restriction may range from patch clearcutting with irregular boundaries for a reduction of visual impact to a complete ban on cutting (Ministère de l'Énergie et des Ressources 1986). The only specific reference to aspen is a prohibition on cutting closer than 40 m to an active beaver lodge.

Except for a few trials (Doucet 1979), regeneration so far has meant either accepting what was coming after cutting or conversion to conifers.

ONTARIO

Current harvest practice in Ontario is a clearcut in both mixedwood and pure aspen stands. Whether the clearcut is a silvicultural clearcut or a commercial clearcut is dependent upon the composition of the stand and available markets. If white birch (Betula papyrifera Marsh.) is a stand component it is usually left standing in harvesting operations. The practice of harvesting mixedwood stands only for the conifer component or aspen stands only for veneer logs is discouraged (Heikurinen 1981). It has also decreased due to better markets and coordination between those harvesting veneer and pulpwood. The size and shape of clearcuts vary from area to area. If roads do not exist in an area the harvest operation progresses as the road extends and results in extensive areas of even-aged forest. To some extent the impact of large clearcuts has been minimized by the provision of wildlife corridors. Areas having an established road system tend to have a better distribution of harvested areas, creating a greater diversity of habitats for wildlife.

When a decision is made to harvest a stand, an active or passive decision in wildlife management has also been made. In Ontario, there are a number of habitat management guidelines which have been introduced over the last decade, most within the last five years. The species for which guidelines have been prepared include moose, deer, furbearers, waterfowl, eagles, warblers, and others. Managers use the guidelines as warranted by their particular situation. For example, consider the effects of harvesting and regeneration on moose habitat. The primary moose range agrees closely with the major poplar area in Ontario. Moose inhabit the early successional stage of stand development up to about 20 years (Timmerman and McNichol 1988). McNichol and Timmerman (1981) suggested that clearcut mixedwood stands do not provide desirable moose habitat, and that scarification and planting fail to provide the advantages of advanced conifer regeneration and residual hardwood cover that existed when only the merchantable conifer was harvested. Areas having residual basal areas of 2.5 m^2/ha each of hardwood and conifer were preferred habitat during January and February due to the quantity and variety of browse species available (McNichol and Gilbert cited by McNichol and Timmerman 1981).

Site preparation for the regeneration of aspen is generally not practiced in Ontario. However, at least one management plan made allowance for the removal of non-merchantable stems by mechanical or chemical means following commercial clearcuts to assure adequate aspen sucker regeneration. The actual need or desirability of removing non-merchantable residuals is dependent upon the quantity of trees that remain following harvesting. Jones (1976) suggested that a residual basal area of 3.4 m^2/ha approached a clearcut, but recommended felling of residual stems if the basal area was as great as 2.3 m^2/ha to encourage regeneration. However, leaving patches of residual trees may be beneficial for moose habitat, particularly in mixedwoods having conifers (McNichol and Timmerman 1981).

Equipment utilized in preparing harvested stands for establishment of conifer regeneration has changed dramatically over the last decade. The use of heavy drags (e.g., shark-finned barrels developed in Ontario during the mid 1960s) has decreased for site preparation, and there has been an increase in the use of shear blades, and implements similar to Young's Teeth, but on mixedwood sites under-utilization of hardwoods is still a problem requiring heavy equipment (Smith 1987). The use of heavy drags significantly reduced the growth and internal stem and root quality of 3-year-old suckers (Basham 1988).

Prescribed burning increased sharply by the mid 1980s with the number of burns nearing 60 per year and area totals approximating 15 000 hectares per year (Gagnon 1987). However, the treatments are aimed at conifer regeneration and not aspen. Aspen sites may be too moist to burn during years with normal weather patterns and the fire situation may be too critical for burning the aspen sites during dry years. Another possible difficulty with burning aspen sites is proper fuel loading to carry the fire across the site. Perala (1974) described similar difficulties on a mixedwood site in Minnesota.

FUTURE DEVELOPMENTS

THINNING

There is interest in commercial thinning to increase yield by salvaging potential mortality and increasing growth of the residual trees, and in precommercial thinning to shorten rotation length. This interest stems from the results of the few experiments that have been done. Young dense stands on medium to good sites respond favorably. Maximum response was obtained four years after treatment (Doucet and Veilleux 1982), but differences were still evident after ten years. Thinning to 1500 stems/ha did not decrease total or merchantable volume increment for the first five-year period after thinning (Table 3) and volume increments increased during the second five-year period after thinning.

Table 3.--Growth response of aspen to thinning.

Stand Data After Thinning					Net Volume Increment (m³/ha)			
					First 5 Years		Second 5 Years	
Age (yrs)	Dominant Height (m)	Residual Density (stems/ha)	Volume Total[1] (m³/ha)	Volume Merchantable[2] (m³/ha)	Total[1]	Merchantable[2]	Total[1]	Merchantable[2]
15	9.4	10,000[3]	81	6	41	10	25	30
		1,500	31	1	36	12	34	41
		750	22	1	27	15	33	41
23	12.5	7,375[3]	154	61	44	48	32	38
		1,500	73	25	48	45	55	55
		750	51	24	38	38	35	36
45	14.6	2,792[3]	210	122	27	34	27	43
		750	101	76	33	32	42	42

[1]DBH ≥ 1.0 cm.
[2]DBH ≥ 9.1 cm.
[3]Control: DBH ≥ 1.0 cm.

Thinning to 750 stems/ha slightly decreased volume increment for the first five-year period, but a recovery was evident in the second period. If this trend continues results will be similar to those in the Lake States (Perala 1978). Even a 45-year-old stand responded favorably to heavy thinning by maintaining net volume increment, and the 10-year DBH increment of the 250 largest trees/ha was 50 percent greater in the thinned plots at 4.8 cm compared to 3.2 cm in the unthinned portion of the stand. This suggests that stands in Quebec can maintain their growth potential longer than those in the Lake States (Schlaegel and Ringold 1971). This is consistent with observations that aspen longevity is inversely related to mean annual temperature (Shields and Bockheim 1981).

Much of the present logging is conducted in mature and over-mature stands 60 or more years of age, so that cull and defects represent a large percentage of the total volume. The main incentive of thinning would be to produce large diameters in a shorter time. Commercial thinning would be particularly attractive if logging methods can be adapted. Thinning could be done as soon as it pays for itself and up to about 40 years of age. In mixedwood stands or in aspen stands with a few scattered conifers, there is evidence that thinning could favor the establishment of softwood regeneration.

Managers might be more reluctant to use precommercial thinning as it requires an investment that would not be recovered until much later in the rotation. However, this treatment will likely have a place in the production of large logs while shortening the rotation, increasing browse production, and providing variety of habitat for game and non-game species. Another benefit of thinning is a possible reduction of defect in the harvested crop. The presence of higher amounts of defect in the lower crown class trees has been reported in several studies in Ontario (Kemperman et al. 1976, Kemperman et al. 1978, Weingartner and Basham 1985).

Economic application of precommercial thinning would require the development of markets for material smaller than the minimum pulpwood diameter, development of appropriate harvesting technologies, and favorable cost/benefit analysis of the treatment. A favorable analysis could result not only from immediate financial return or increased timber values in the future, but also, from improvements in wildlife habitat, and other features such as recreational value and aesthetics.

The response of five-year-old sucker regeneration to precommercial thinning is substantial and fairly immediate. Five years following treatment of three stands stem volumes of released trees were 29 percent to 45 percent greater than unreleased trees of the same volume prior to treatment (Weingartner 1987). A similar response to thinning for diameter growth was reported by Bella (1975).

Equipment suitable for harvesting small dimension material has been proposed, and/or developed and tested in various throughout eastern Canada locations. In Ontario, the CFS produced a prototype brush harvester based on the Pallari rotary shear, integrated with a drum chipper (Sutherland 1985). An advantage of the design is the low speed (40 rpm maximum) of the hydraulically driven shear blades, reducing the danger of flying fragments if the implement contacts a rock. Another approach is to use a chipper-forwarder (Stokes and Sirois 1986) in conjunction with a feller buncher. A feller buncher developed in Ontario consisting of two counter rotating saws with an accumulating head achieved production rates close to 850 trees per hour and more than 17 green tonnes per hour in a sycamore plantation in Alabama (Frederick et al. 1986).

Interest in the 'greenhouse effect' or global warming is increasing steadily. The full impact of this warming process on North American forests is unknown, but it may have substantial impact on the aspen resource even during current rotations. If climatological predictions (temperature increase and precipitation decrease) prove correct what effect will it have on aspen production on those sites that are slightly drier than the best sites? Site quality and growth of aspen have been related to moisture availability in numerous studies over the years (Fralish and Loucks 1975, Strothmann 1960, Wilde and Pronin 1949). If slow growth is equated with increased defect these sites may need to be actively managed to produce suitable yields of quality material for industry. One method to achieve this end is by thinning which allows for the redistribution of water and nutrients to the crop trees.

GENETIC IMPROVEMENT

A program of genetic improvement of poplar in Quebec began during the mid-sixties (Comité de recherche en génétique forestière 1971). Aspen has attracted only minimal attention in this program, because other poplars are easier to reproduce vegetatively and their growth rate is usually better. A survey program has been started, mainly in the northern regions, to identify superior clones. These would either be used directly to produce improved seedlings, or as material for the development of hybrids with other native or exotic aspens and other poplars. Potential superior clones are tested for their resistance to Hypoxylon canker. The objective of the program is to develop planting material better adapted to somewhat less fertile sites or to heavy soils such as those of the Clay Belt in northwestern Quebec[3].

MANAGEMENT IN MIXEDWOOD STANDS

Increased use of aspen will mean that the mixedwood stands will have a larger proportion of aspen in the second rotation. This may not be entirely acceptable as softwoods are in great demand. Careful planning will be needed to decide which species is to be favored in each case. Although managers usually prefer pure stands, because they are easier to manage and harvest, they will have to deal more and more with mixedwood stands in the future, and they will have to act accordingly. Many questions on the management of aspen in mixedwood stands will have to be addressed. For example, would it

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[3]Gilles Vallée, Service de l'amélioration des arbes, ministére de l'Énergie et des Ressources, Québec. Personal communication.

be practical, for example to cut aspen a few years before the softwood harvest to minimize suckering in areas where conifers are to be favored?

Information on the management of aspen in mixedwood stands is limited; however, articles dealing with extensive and intensive management of mixedwood provide some indication of management options.

In one scenario, aspen is present in spruce-aspen stands at low density after harvest of the merchantable trees. The next rotation is dominated by aspen with understory spruce as advanced regeneration or seedlings from seed trees forming the nucleus of a spruce stand in the following rotation (Schreiner 1959). Berry (1982) reported the results of establishing conifers by direct seeding in a mixedwood stand followed by removal of the aspen canopy, 28 years later, and the resultant mixedwood stand that developed during the next 30 years. The result was a stand of aspen and conifer of similar size.

A reference for intensive management in Sweden describes the gradual reduction of hardwood density via precommercial and commercial thinning in a conifer planted mixedwood. The method applies precommercial and commercial thinning to gradually remove the hardwood component and reduce the spruce component to approximately 2500 stems per hectare during the first 20 years of the rotation resulting in a pure conifer stand (Alriksson 1983).

The feasibility of silvicultural operations in pure aspen and mixedwood stands is dependent upon the continued and increasing market acceptance of aspen, development of appropriate silvicultural systems, and favorable economic cost and benefit of the treatments. The extensive areas covered by aspen in eastern Canada warrant thorough exploration of all the above aspects.

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MANAGEMENT OF ASPEN IN THE CENTRAL ROCKY MOUNTAINS: AN APPLICATION OF MULTIPLE USE SILVICULTURE

Wayne D. Shepperd[1]

ABSTRACT.--Aspen is the only hardwood species currently being managed in the Rocky Mountain Region. The climate and successional behavior of aspen in this region make it a true multiresource species. Growth and stand characteristics of aspen in the Rockies differ from those of aspen elsewhere. These differences allow aspen to serve a variety of resource roles. A number of alternate silvicultural strategies are being used to manage aspen for these multiple resource outputs.

INTRODUCTION

Aspen (Populus tremuloides) the major deciduous tree species in the Central and Southern Rocky Mountains, is an important component of our forested lands. It is in increasing demand as a source of firewood and wood fiber, but more importantly, provides critical habitat for wildlife, excellent understory forage for livestock, and is an essential element of scenic vistas for which the Rockies are known. To understand how aspen in the Rockies is managed for these diverse uses, we first need to understand the climatic and ecologic behavior of the species in this region. I feel it is appropriate to begin with an explanation of the silvics and growth habit of aspen in the Central Rockies.

GROWTH AND STAND CHARACTERISTICS

Aspen in the Rocky Mountains has some unique growth and stand characteristics that affect its management (Shepperd 1982). First of all, there is a lot of it. Aspen comprises approximately 20 percent of the inventoried forest land in the U.S. Forest Service's Rocky Mountain Region. The species occupies a broad elevational and ecologic range, occurring as both a seral and stable overstory associate of many Rocky Mountain plant communities (Alexander 1985). Large, expansive, pure stands of aspen occur on the western slope of the Continental Divide in areas outside the natural range of lodgepole pine, a primary competitor. Elsewhere, aspen exists as a riparian species, or as a seral component in mixed aspen/conifer stands. Although short-lived compared to conifers, aspen can initially out-produce them on similar sites.

Aspen also lives longer in the Rockies than in the Lake States. Most stands are between 80 - 110 years of age. It is also not exclusively even-aged. Approximately 20 percent of the stands sampled in a study at the Rocky Mountain Forest and Range Experiment Station were either two-aged, or multi-aged, giving them an irregular vertical structure (Shepperd 1982).

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Aspen has a reputation of being susceptible to disease and damage (Hinds and Wengert 1977, Walters et al. 1982). This susceptibility is partially responsible for natural thinning in aspen stands, which allows more growing space for surviving healthy stems. On the average, mature aspen and conifer stands contain similar amounts of volume defects (Shepperd and Engelby 1983).

SILVICAL CHARACTERISTICS

Aspen is one of the most intolerant species we have in the Rockies. It produces abundant crops of viable seed (Schopmeyer 1974), but unfortunately, the stringent requirements of bare mineral soil and a constant supply of moisture throughout the first growing season (McDonough 1979) make aspen seedlings rare enough to be dismissed as a regeneration method for managed stands.

Most aspen stands in the Rockies reproduce by root suckering following partial or complete mortality of overstory stands (Shepperd and Engelby 1983). The result is large groups of genetically identical ramets (clones) that may sometimes be many hectares in size. This clonal growth habit gives a unique twist to management of aspen in the Rockies, since the genetic unit is a large group of trees, a single stem. Because they represent a single genotype, entire clones can be expected to respond similarly to management. Therefore, it is important to be able to recognize individual clones and their growth differences.

There are a number of things that can be used to identify clones (Morgan 1969, Shepperd 1982). Neighboring clones will flush their leaves at different times in the spring, and turn at different times, or be different colors in the fall. The bark of some clones is pure white, while others will be cream colored, grey, or even greenish. Some clones self-prune their dead branches, others retain them on the stems. Differences in the color and texture of summer foliage can also help locate clonal boundaries, as can the presence or absence of suckers in the understory. Conversely, the advancement of regeneration into open areas makes it appear as if two clones exist where in fact, there is only one.

There are basically two successional pathways a new aspen stand can follow in the Rockies. In both cases, a dense stand of young aspen sprouts will probably initially occupy the site after a fire or other disturbance has obliterated the previous stand (Shepperd and Engelby 1983).

If a coniferous seed source is present, young conifers will soon begin to establish themselves under the aspen. The aspen then acts as a nurse crop for the more tolerant conifers (usually spruce, subalpine fir, or Douglas-fir, but in some cases ponderosa pine), the result is a mixed aspen/conifer stand. If succession is allowed to continue without further disturbance, a pure climax conifer stand will eventually develop on these sites. However, some aspen can persist as a suppressed understory, and will re-occupy the site if the conifers die or are removed.

The other successional pathway occurs when there is no conifer seed source in or near the aspen stand. In these cases, the aspen grow to maturity and beyond and eventually begin to die, either slowly a few stems at a time, or quickly through a general overstory breakup. At this point the root system will respond to the death of the overstory with new sprouting, or an existing sapling understory will release to continue the clone. Either an even-aged or uneven-aged stand might result from this scenario. In other cases, the root system may be incapable of sufficient suckering to overcome biotic factors that kill new suckers, and the clone will die and be replaced by other vegetation.

MANAGING ASPEN IN THE ROCKY MOUNTAINS

Management practices for aspen forests in the Central and Southern Rocky Mountains have not evolved in the same manner as those for conifer forests in this region. Historically, low demand for aspen wood products resulted in little interest in intensive management. Prior to 1976 aspen accounted for only 2 percent of the annual timber harvest in the Rocky Mountain Region (Mathison 1976), even though aspen occupies about a third of the forested area in Colorado alone. Active management of aspen forests occurred only where local commercial markets existed for aspen products such as match splints, excelsior, paneling, sawn shakes, mine props, pallets, fence poles, and other specialty products (Koepke 1976). In most cases, only large trees free of internal defect could be used for these products, further limiting the types of stands that could be commercially managed.

In 1983, the aspen management picture abruptly changed when the Louisiana Pacific Corporation announced construction of two waferwood mills in Colorado that would utilize aspen. This market for aspen provided a means to effectively and economically manage a much greater portion of the aspen resource.

However, effective management of the aspen resource in the Rockies involves more than the existence of a commercial demand for the resource. People who live in and visit the Rocky Mountains have an emotional attachment to aspen. They photograph aspen, recreate in aspen, graze their livestock in aspen, admire or hunt animals in aspen, and purchase wood products derived from aspen.

Therefore, silvicultural management plans in the Rockies are not geared just toward producing maximum fiber growth, nor are they restricted only to stands containing commercial volumes. Instead, silvicultural prescriptions are designed to meet a variety of multiple resource needs. Several regeneration techniques are used. Each takes advantage of aspen's intolerance to shade, its propensity to root sucker, and its ability to self-thin as it matures.

Stands with an existing overstory of commercial size and quality can be regenerated by commercial clearfelling. Currently, the largest market for aspen in Colorado is waferboard, but it is also harvested for matches and paneling. Trees are logged by traditional chainsaw felling, limbing in place, and skidding with rubber-tired choker skidders, or alternatively by mechanical shearing and bunching, grapple skidding, and delimbing at landings. Both logging techniques result in successful suckering, if all residual stems are cut, and concentrations of logging slash are avoided.

Hand felling and clearing is also used to regenerate non-commercial aspen stands for wildlife habitat, or to perpetuate aspen for scenic purposes. The slash from the original stand may be either scattered in place, or disposed of as fuelwood, depending upon accessibility and local species preferences for firewood. The types of stands treated in this manner are usually poorly stocked, inaccessible to logging equipment, or are in localities with no viable aspen market. Often, such stands are in critical need of regeneration to maintain the presence of aspen in the local ecosystem.

Using a bulldozer to clearfell non-commercial aspen stands is another technique which we have been studying. We have found bulldozing to be successful if the trees are pushed over with the blade kept above the ground. This avoids excessive damage to the lateral root system, but at the same time isolates major lateral roots and stimulates additional suckering. The technique should be used cautiously, however bulldozing heavily stocked stands can produce large concentrations of slash that will severely inhibit sprouting.

In spite of aspen's reputation as a natural firebreak (Fechner and Barrows 1976), prescribed burning is used in some cases to kill the existing overstory and allow a new stand to sprout (Schier and Campbell 1978). Burning works best in stands with coniferous or shrub understory fuels to carry the fire. It is used most often in the central Rockies to regenerate small, isolated clones surrounded by oak or sagebrush. The fire is set in the brush and allowed to build in intensity before running into the aspen. This not only results in a better kill of existing aspen, but stimulates peripheral roots surrounding the clone to sucker as well, thus expanding the clone.

Partial cutting could theoretically regenerate some clones, especially those with two or more age classes in the understory. However, most clones need a major disturbance to trigger suckering. Individual tree selection or shelterwood harvest methods should not be used in stands managed for sustained fiber yield. Residual stem mortality is usually high following a partial cut. Those stems that do survive will release and grow at an increased rate, even though many will be damaged and infected from logging. These trees cannot be harvested in a later entry without damaging the new stand and must remain in place, thereby sacrificing both present and future economic return for that portion of the stand.

Timber is not the only resource hurt by partial cutting mature aspen. As remaining trees die and fall, they may also impede animal movement, create unacceptable fuel loadings, and endanger recreationists.

An acceptable alternative in situations where an uneven-aged stand structure is desired would be to use a group selection cutting method. Carefully planned and executed group selection cuts will avoid most of the above problems. Stands in roadside scenic corridors and those providing critical thermal or hiding cover to animals would be good candidates for this system.

One final option, which is often overlooked, is to do nothing. Some aspen stands in the Rockies are capable of regenerating themselves without our intervention. All we need to do is identify them and leave them alone. Often the question managers must ask when considering silvicultural alternatives is not "Will the stand regenerate?", but rather "Will the naturally regenerated stand meet our management objectives for the area?"

Several additional factors need to be considered when managing Rocky Mountain aspen. Like other tree species in the Rockies, aspen is shallow-rooted and susceptible to windthrow. Recognizing high wind risk areas (Alexander 1974), is necessary to plan a harvest sequence that will avoid unnecessary exposure of residual stands to wind.

Excessive damage to the clonal root system must also be avoided. While research has indicated there is a beneficial effect from some disturbance, experience has shown that heavily used skid trails and landings often will not regenerate.

Finally, care should be exercised when attempting to regenerate stands located in physiographic positions or vegetation types with high water tables. Transpiration by existing overstories has apparently maintained the water table in these areas below the root zone. Removing the aspen overstory in these areas allows the water table to rise and greatly inhibits suckering.

FACTORS AFFECTING SUCKER SURVIVAL

There are a number of factors that can affect aspen sucker survival following initial establishment. Browsing by large animals can be severe enough in some cases to drastically reduce stocking and affect the form of the surviving stems. Experience has shown that regenerating enough aspen in an area to provide more suckers than the animals can eat will avoid excessive damage. Concentrating harvest activities in one area also minimizes road building and logging costs, and reduces the period of time wildlife may be disturbed. Placement of salt blocks and water can also be used to control animal use. Extreme cases may require fencing for a few years until the sprouts are out of the reach of the animals. Small animals can also affect regeneration. Bark girdling by rodents during high population cycles can severely damage suckers on a local scale, but is not a serious factor Region-wide[2].

Sucker diseases are present in most sprout stands, but can completely wipe out stands as old as 10 years of age. Again, the problem has not been widespread, but has severely affected some areas.

Snow damage is yet another factor influencing sucker survival in the Rockies. Snow depths can exceed 2 m in many aspen stands and easily contain over 60 cm of water. Branches can be stripped and stems broken if suckers are trapped in crust when the snowpack settles (Crouch 1983). Snow damage

[2]Personal communication, U.S. Forest Service, Rocky Mountain Region, 1985.

does not occur on all areas, or during every year, but it can seriously affect the stem form of young aspen. Although branch wounds can callous over if not infected and bent stems may eventually recover[3], repeated damage can weaken the overall vigor of a stand and affect future yields.

CONCLUSIONS

This paper has described the stand and growth characteristics of aspen growing in the Central Rocky Mountains, and has briefly discussed silvicultural options available to manage aspen for a variety of resource uses. Implementation of multiple resource management of aspen relies upon several key operations, which are linked together much like a chain. A breakdown or failure of any will result in the failure of the entire process. Accurate inventory information and input from other disciplines affected by aspen management should be evaluated and used to develop a prescription that reflects the desired management objectives for a stand. A properly executed treatment is essential to implement the prescription. The best prescription will do no good if improperly applied. Finally, accurate, long term records are needed to insure that future activities within an aspen stand are consistent with the original prescription and are properly scheduled. Proper multi-resource management of the aspen resource in the Central Rocky Mountains is possible only if resource managers from all disciplines work together.

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ASPEN UTILIZATION IN THE NORTHERN UNITED STATES

David I. Maass, Lloyd C. Irland and Stephen D. Salisbury[1]

ABSTRACT.--Aspen is an important resource to the northern United States and in Quebec and Ontario. Roundwood use for pulp in the Lake States has remained stable at 2 million cords since 1981, while use for flakeboard has increased five-fold. Despite the near doubling of use in this decade, real stumpage prices for aspen have remained stable, and mill delivered prices have declined. The pulp industry is less cost and supply sensitive than the flakeboard industries. Substitutions of other species will occur when aspen supply declines. Resource decisions in the future will be driven by both markets and politics.

INTRODUCTION

Aspen has gone from "Weed of the North" to "Queen of the North" in the last 30 years. Products and processes have been developed to take advantage of this enormous, fast growing, available resource. Now we are concerned about the future of the resource, because many people and industries have become so dependent on it.

ASPEN UTILIZATION

Aspen is used for a wide variety of products. It may be safe to say there are few other species that can be adapted to the gamut of lumber and paper products produced today. It has utilization not only for high quality paper, but as a building product in oriented strandboard (OSB), waferboard, hardboard, insulation board, pallets, furniture and veneers for food packages. Its traits of light weight and color, and fiber length make it desirable for these many uses. Abundance in the Lake States makes it a valuable raw material.

Table 1 characterizes our estimates of how aspen is utilized in different product lines within the Lake States and provinces of Quebec and Ontario. These rough estimates examine magnitudes of uses and are not definitive volumes. Minnesota is the largest user of aspen in the United States with its strong flakeboard industry. Wisconsin has the greatest use of aspen for pulp. Interestingly the flakeboard use exceeds pulpmill use in all states but Wisconsin. Canadian figures are for illustrative purposes.

PULPWOOD

Hardwoods dominate pulpwood use in the Lake States, whereas it is about evenly split with softwood in the Northeast (Haynes 1988). If hardwood predominates, aspen makes up a significant portion of the hardwood. In 1986, aspen made up 2.2 million of 5.4 million cords (40%) of softwood and

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Table 1.--Estimates of aspen utilization receipts (M cords).

State/Province	Pulp	OSB/Waferboard	Lumber	Other Uses
Minnesota (1988)[1]	511	905	240	170
Wisconsin (1986)[2]	1035	312	158	125
Michigan (1986)[2]	296	533	151	75
Maine (1986)[3]	156	201	5	0
Quebec (1986)[4]	185	379	50	200
Ontario (1984)[5]	500	549	33	300

[1]John Krantz, Minnesota DNR.
[2]Estimates from Blyth and Smith, 1988.
[3]MFS Timber Cut Report.
[4]Parent, 1987.
[5]Anonymous, 1987.

hardwood roundwood received at mills in the Lake States (Blyth and Smith 1988). Whereas aspen makes up less than 5 percent of the pulpwood in the Northeast (Widmann 1987).

Increases in aspen utilization have taken place primarily in the newer non-veneer plywood market and not in traditional pulpmill markets. Blyth and Smith (1985 and 1989) report aspen utilization for pulpwood to pulpmills had remained steady around two million cords per year since 1981 in the Lake States. Meanwhile aspen use for flakeboards has risen five-fold from 0.382 to 1.542 million cords per year.

Individual pulpmills, however, have reported both absolute and percentage increases in aspen use. Three pulpmills have closed since 1981. Abundant supply, proximity to the mills, and cost are the cited reasons for increased use. The market for high quality paper, especially supercalendered, has increased the demand for hardwood pulp. The value of aspen for pulp has been the longer fiber length and white color which requires less bleaching. Ontario has not readily adopted these new technologies and has not extensively used its aspen resource (Woodbridge, Reed and Associates 1987). Quebec is probably in a similar situation.

PLYWOOD AND VENEER

Aspen is beginning to play a more important role in the plywood industry which is recognizing its ease of sanding and finishing and its attractive price. Many small manufacturers in the region are making specialty plywoods and veneers for a variety of applications from aspen now. As the more preferred hardwoods increase in prices, and as aspen becomes more familiar to customers and users, this can be expected to increase.

RECONSTITUTED STRUCTURAL PANELS

Because of its abundance, low cost, whiteness, and light weight, aspen was the original species used for OSB/Waferboard and remains the staple species for this product line. It could even be said that the product was invented to utilize vast reserves of aspen in Ontario which at the time had only limited markets.

Reconstituted panels are subject to a confusing terminology that has yet to settle down to general acceptance. The American Plywood Association (APA) calls them "nonveneer structural panels". The US Forest Service uses the term flakeboard for particleboard, waferboard, oriented strandboard and medium density fiberboard (MDF). Regardless of name, the original advantages of aspen for this product have not diminished. Even the cost advantage has held up in the face of dramatic increases in consumption. In Maine, where aspen was in less ready supply in our more mixed stands, one waferboard plant worked extensively with spruce-fir budworm salvage wood in its furnish as a way to utilize this superabundant and low-cost fiber. This switch occasioned some production headaches.

National market dynamics for this class of products have been dramatic. Based on cost advantages, these panels have taken share from veneer structural plywoods. With rapid market growth, a continuous stream of improved plants has come on line, each with lower unit costs than the last. The early plants were about 100-120 million square feet (MMSF) in capacity, and several more recent ones are as large as 300 MMSF. This is the same phenomenon observed during the glory days of rapid growth in softwood plywood in the '50s and '60s. As a result, waferboard pricing has been driven downward even in current dollar terms (Fig. 1).

The OSB/waferboard product field has evolved slowly as makers have tried to distinguish niche markets and add value to the basic commodity product. This has resulted in a range of overlaid, textured, and machined products designed for specialty uses.

The boom in OSB/waferboard is not abating, but it must reach a limit someday. For the North, this appears to have already occurred as the pace of capacity expansion has slowed (Table 2). We attribute this to the need of major manufacturers to build closer to the large markets in the South and West and to place mills at a greater distance from intensely competitive Canadian plants.

The increased demand in aspen in the last ten years in the Lake States has resulted from OSB/waferboard manufacturers. There has been a five-fold increase in aspen utilization.

OSB/waferboard producers prefer 100 percent aspen and most would still be doing so if possible. Blyth and Smith (1988) report 14 percent other species and 6 percent residues for mills in the Lake States. Industry leaders spoke about the need to switch to softwood, basswood or birch as necessary because of the price of aspen. Most every mill has seen small but steady increases in price. Some mills have offered a 20 percent premium in order to achieve the supply they want. Quality is not seen as a problem to date.

Table 2.--Flakeboard capacity--Lake States[1].

Year	Number of Mills	Million Square Feet (3/4" basis)
1981	7	520
1982	8	780
1983	9	860
1984	9	860
1985	11	1050
1986	11	1050
1987	12	1330

[1]Source: Blyth and Smith (1983, 1984, 1985, 1986, 1987, 1988, 1989).

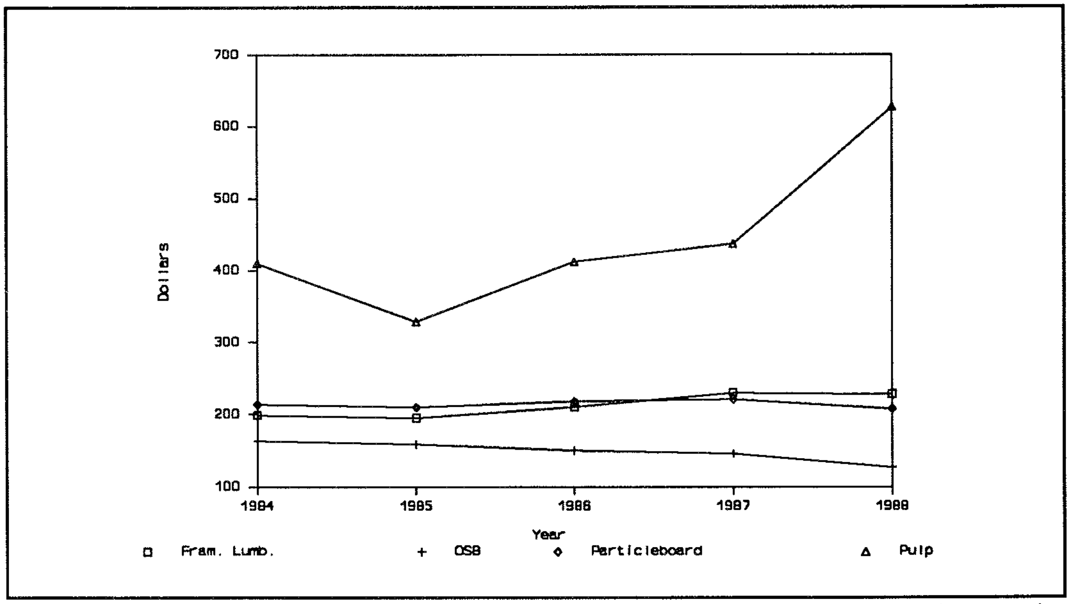

Figure 1.--Summary of product price trends (Louisiana-Pacific Corp. annual reports).

For these plants, the cost of raw material makes up a greater portion of the cost of manufacturing than for pulp and paper manufacturing. As such, these mills will recognize more quickly the effect of small price increases. Generally, manufacturers of OSB/waferboard have lower added value products, are less able to substitute other species and more technologically rigid than pulp and paper manufacturers. This will cause them to be more sensitive to changes in cost, supply, and quality. As supply tightens and costs increase, we see innovations allowing these manufacturers to become more flexible in their species mix. Additionally, there will be more work on development of specialty products.

LUMBER AND RELATED PRODUCTS

Aspen is a traditional specialty hardwood for applications in which light weight, light color, low cost, and limited strength are suitable. It has been used in everything from clapboard siding to moldings and novelties, with many variations in between. In our area, some specialty millwork operations are finding increasing acceptance of aspen moldings competing with pine at a lower price and offering the advantage of no pitch problems in finishing. At least one Midwestern manufacturer is offering an attractive v-match wall panelling product in a range of species, including aspen. Many smaller hardwood mills occasionally saw aspen grade lumber, though the term "poplar" in the east has been taken over by Yellow poplar lumber.

It appears to us that in much of the region, a major user of aspen lumber is the pallet industry, especially where durability is not required. This application obviously avoids difficulties with staining and incipient rot. A related application is that there is a strong market in New England for aspen landscape ties, though aspen does not treat at all well. Their light weight and low price have made them a popular item.

NEW PRODUCTS

Aspen's low cost, abundant supply, and desirable traits have spawned a range of new product uses including applications as diverse as chopsticks and extruded door parts. The announcement of MacMillan Bloedel's proposed plant in Minnesota making this extruded product is especially exciting (Wall Street J, July 12, 1989). We can anticipate a continuing stream of new and unusual applications for aspen in the future.

EXPORTING ASPEN PRODUCTS

Based on the extensive familiarity of European wood users with similar Populus spp., we think that there ought to be export development potential for well manufactured aspen products from the Northeastern USA. Also, with trade channels developing rapidly into the Pacific Rim for northern hardwoods, opportunities in those nations may be improving as well.

GENERIC ISSUES IN UTILIZATION

Aspen has many favorable qualities in a range of panel and other solid wood uses. These do not appear to have been fully appreciated and exploited, because of our ample supplies of competing softwoods in the past and our abundant supplies of furniture grade hardwoods. To a degree we are in a chicken-and-egg situation. A large volume user of aspen grade lumber or cut parts would have difficulty in assuring reliable sourcing. At the same time, until volume markets emerge, mills have little incentive to set up for high volume and value-added production.

Supply of quality logs has always been a problem for aspen mills. One landowner in Eastern Maine does not even attempt to grade out aspen logs anymore, because of the difficulty of predicting log grade in the field. There was just too much variability in staining and rot. This general problem is being mentioned regularly by all aspen users around the region, as they expect older aspen to exhibit more staining. One user also suggested that much of the mature aspen remaining to be cut is on marginal sites, which also may yield higher proportions of defect. These problems are not well defined empirically, but they do seem to pose a significant obstacle to large expansions in aspen production for quality solid wood uses. On the other hand, the finishing quality of aspen suggests that it could occupy an important position in many uses that allow painted finishes and in interior parts.

Manufacturing processes for different products have very different requirements for aspen use and technical flexibility. Because of these, some industries will be more cost conscious and supply and quality dependent than others. These factors will determine the market dynamics in the future as aspen becomes scarcer (Table 3).

We see the pulp industry in the Lake States as currently using 40 percent aspen for their species mix. They can also substitute a variety of species and change the processes to move away from aspen, if necessary. Raw material for this industry represents a smaller percentage of the cost of manufacturing than other industries. However, paper, the high valued final product, is dependent on the particular properties of aspen and changes will mean higher cost of raw material and in processing. For these reasons, we see the pulp industry as having moderate sensitivity to the cost and supply of aspen.

OSB/waferboard products, on the other hand, are very dependent on aspen supply, quality and properties. This industry would have some difficulty in substitution. Raw material cost represents a greater percentage of the cost of manufacturing than paper. Therefore, we see high sensitivity to cost and supply of aspen in this industry.

Lumber, pallets and MDF industries use relatively little aspen currently. They have a great deal of flexibility to substitute and use relatively small pieces. Their final product is a commodity item and very dependent on low cost raw material. We see this industry as highly cost sensitive and will very likely substitute other raw materials.

Plywood and veneer industries use little aspen now, but have found favorable uses for aspen as a raw material. These industries can substitute readily and develop new product lines based on sources of available raw materials. This industry has a high level of flexibility. We believe that this industry will have a low sensitivity to cost of aspen.

Table 3.--Aspen utilization patterns by product--Lake States.

	Percent Aspen	Technical Flexibility	Cost Sensitivity
Pulp	40	Moderate	Low
OSB	100	Low	High
Lumber/Pallets	5	High	High
MDF	5	High	?
Plywood & Veneer	10	High	Low

ASPEN ECONOMICS

Aspen demand has been increasing in the Lake States. Aspen production for both pulp and flakeboard products have increased from 2.3 million cords per year in 1980 to 3.7 million cords in 1986 (Blyth and Smith 1982, Blyth and Smith 1988). As can be seen in Figure 2, real prices in Wisconsin for aspen stumpage have declined slightly since the 1950s, but have held steady in the last seven years. Price jumps in local markets did occur when new mills were established. Delivered prices have declined generally (Ulrich 1988). This reflects the abundance of the resource and improvements in efficiencies in harvesting and delivery of wood with economies of scale. Minnesota stumpage prices in real dollars have been nearly constant since a short rise in 1980.

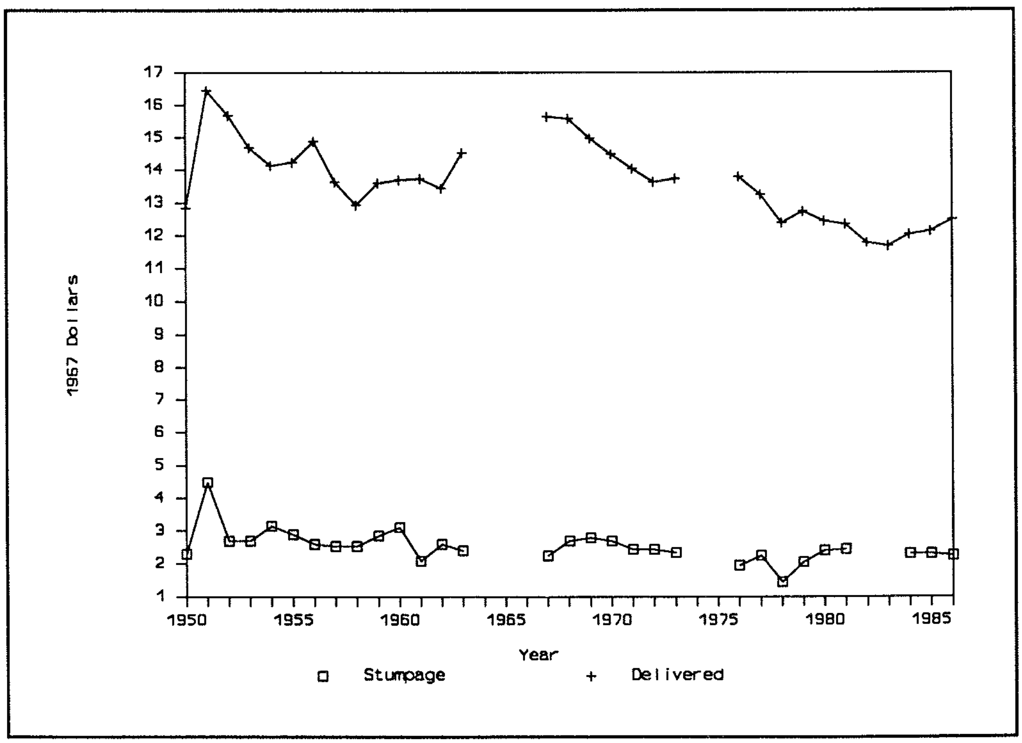

Figure 2.--Wisconsin aspen pulpwood prices.

LESSONS LEARNED FROM SPRUCE-FIR TIMBER SUPPLY PROBLEMS

In Maine, we have learned some lessons about timber supply of a critical resource. Spruce-fir in Maine occupies 7.8 million acres and supports a $3 billion pulp and paper manufacturing industry. We are now in the inventory decline of this critical resource due to an old age and insect problem (Irland et al. 1988). There was a decrease of 9 million cords of spruce and fir between the two inventory periods of 1971 and 1982. More mortality occurred after 1982 as the spruce budworm ate its way through the forest. The mature and overmature stands which had resulted from the spruce budworm epidemic of the 1910s aggravated the problem. How has the industry and the state coped with this situation?

WITH DECREASED ASPEN SUPPLY, SUBSTITUTIONS WILL OCCUR

By way of example, hardwoods have substituted for spruce and fir in pulp mixes in Maine. Figures 3 and 4 show the leveling in spruce and fir pulpwood use and the increase in hardwood pulp since 1980. In 1979, spruce-fir made up 52 percent of the roundwood at the pulp mills and in 1986 that had declined to 45 percent. Fortunately during this period there has been a demand for pulp and paper made with a greater amount of hardwood.

Figures 5 and 6 indicate that real stumpage and delivered prices for softwood pulp have remained constant since 1960. Hardwood pulp stumpage prices have increased slightly, while delivered prices have declined.

QUALITY WILL GET WORSE BEFORE IMPROVING

As with other species that have suffered from age class problems, the aspen resource will likely decline in quality. Insects and diseases that invade older aspen stands will find a ready resource. Furthermore, old age trees that usually encounter a variety of butt and stem rots and cankers will increase in number. Stands that are most accessible and are on better quality sites will soon be harvested. This means that older stands on marginal sites will be left and will have a higher incidence of problems.

After these older stands have been harvested, converted naturally or intentionally, the industry can look for improving quality of clear fast growing wood. Management in the future will probably identify the best aspen sites and dedicate aspen management on these. This means a general improvement and consistent level of quality well into the future.

BEYOND 2000, STANDS WILL BE YOUNGER, FASTER GROWING

When the new developing stands emerge into merchantable size classes, they are likely to be faster growing. Management inputs such as planting, weed and pest control, fertilization and thinning will yield higher quantities of wood per acre and more merchantable stems per acre. This means that older yield tables will no longer be applicable and that the same quantity of wood can be grown on fewer acres. Stem sizes will increase if the stands are allowed to grow for the same period of time.

FOREST CONDITIONS OF THE 1990s WILL NOT RECUR

The conditions that brought 12 million acres of aspen types to maturity late in this century will not happen again. We recognize that the current level of cut and the mix of management strategies are different from the ones that brought about this most prolific and useful resource.

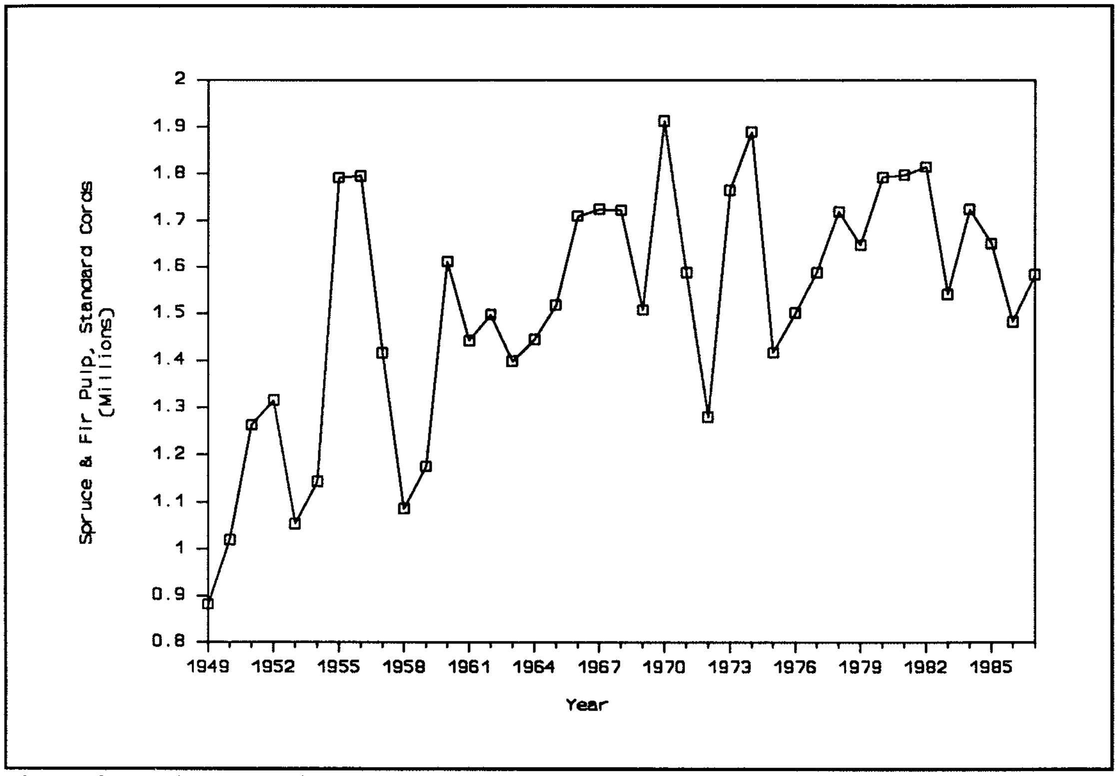

Figure 3.--Maine statewide timbercut spruce-fir pulp.

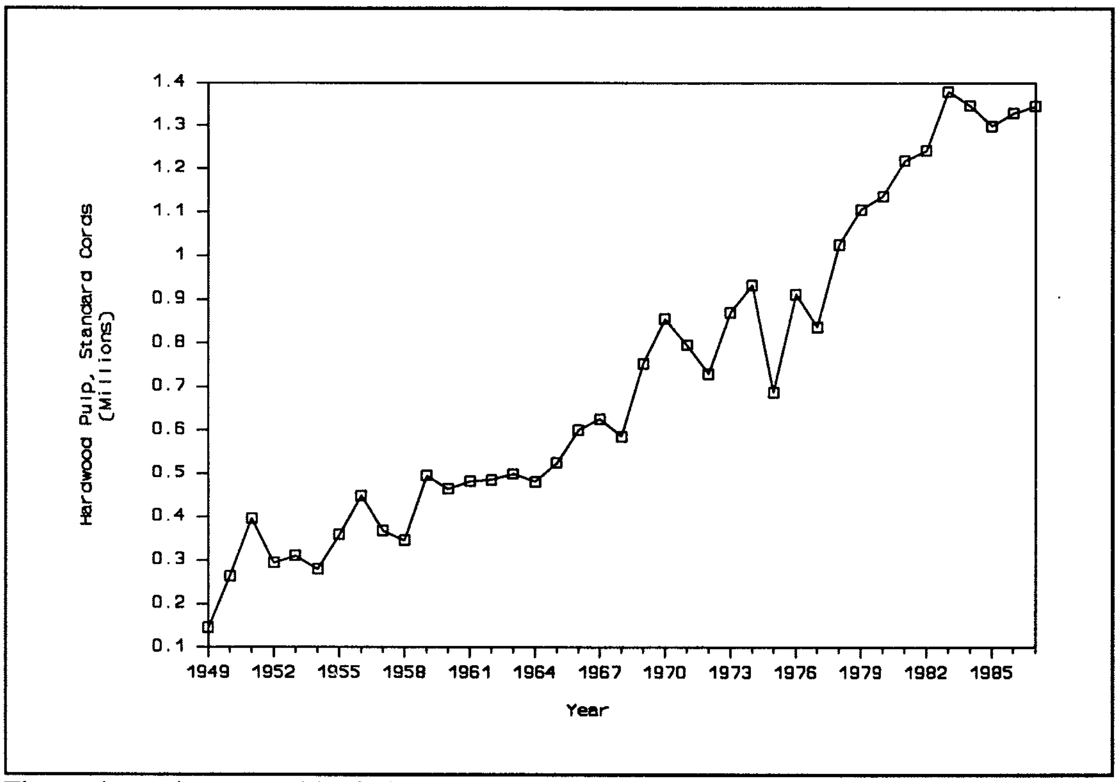

Figure 4.--Maine statewide timbercut hardwood pulp.

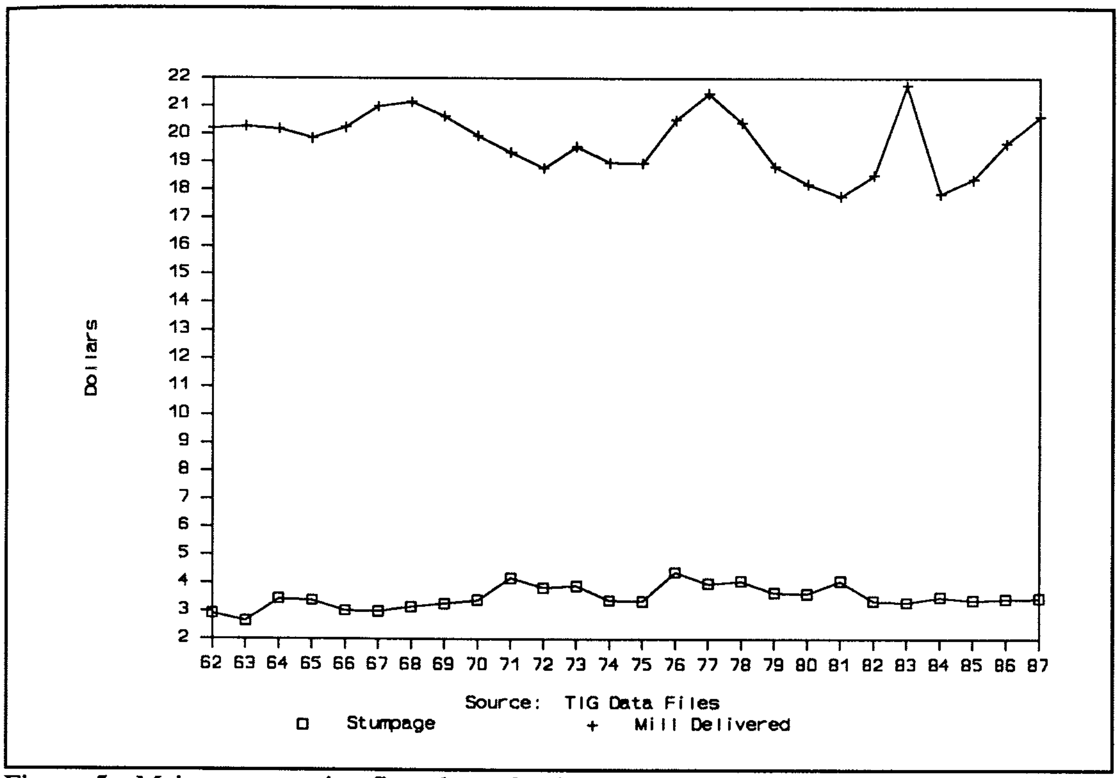

Figure 5.--Maine spruce-pine-fir pulp real prices.

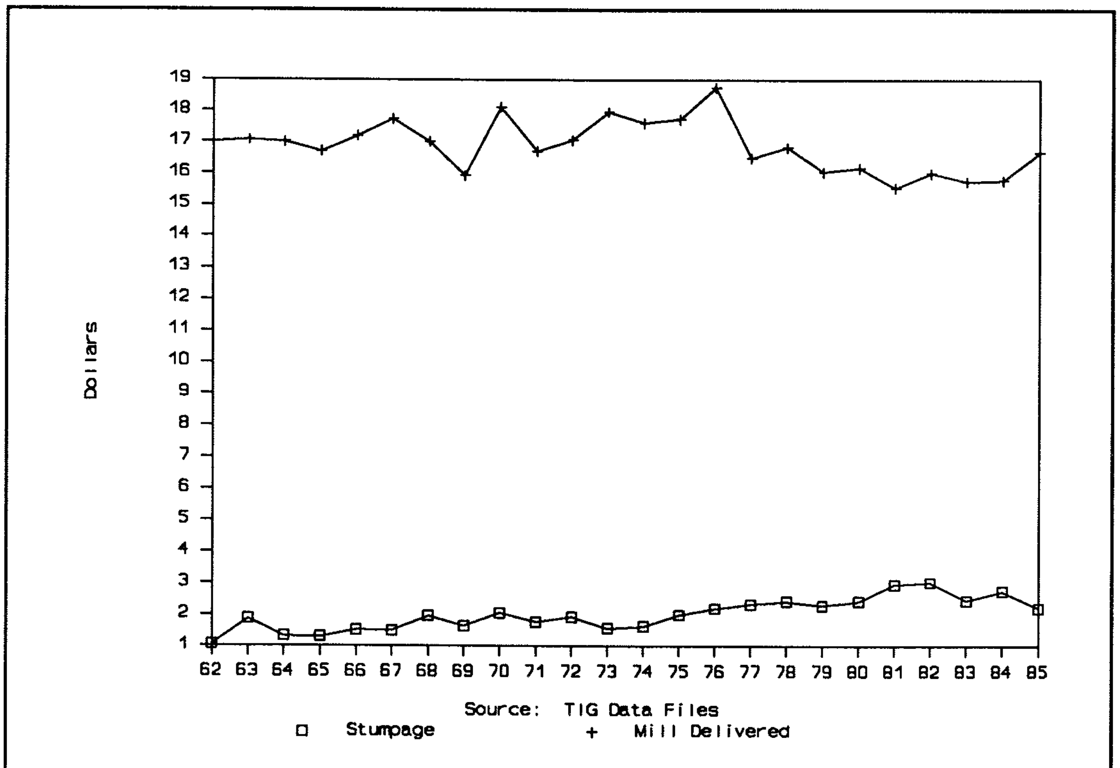

Figure 6.--Maine hardwood pulp real prices.

EXPECT LONGER TRANSPORTATION DISTANCES

In an oversupply situation harvesting occurs generally on the most accessible and closest sites to the mills. As the aspen supply tightens transportation distances will increase perhaps to astonishing lengths, even in this day of softwood coming from the Prairies. Imports from Canada may become more common. For the state and county governments, this will require improved roading systems that recognize these distances and the increased use of major highways leading to the mills.

MARKETS ARE IMPROVING FOR LOW QUALITY MATERIAL

We have seen in New England, an improvement in local markets for low quality and currently submerchantable stems. Biomass chipping for fuel for cogeneration, landscape ties and other products which utilize small or poor quality wood have increased in recent years and have utilized available supplies of wood.

OUR KNOWLEDGE IS GREATER, BUT STILL LIMITED

We have a better understanding of the biology of aspen and its pests. We have silvicultural and managerial techniques available to us to better manage the forest for the goals of the landowners. Whether the aspen resource is managed to produce more aspen is another question. The collective actions made will have as great an influence on the resource as management of government lands.

DECISIONS ABOUT THE ASPEN RESOURCES WILL BE BOTH MARKET DRIVEN AND POLITICAL

Because the aspen resource is of such importance to the Lake States and to Minnesota, in particular, decisions about how the resource is managed will be made by both forest managers and the public. The public has had greater participation in the National Forest Plans than in the past. There is little doubt that they will come to expect similar participation on state and county lands. Even the industry will not be immune, as their activities are scrutinized to a greater extent.

The public seems to like aspen. It recovers a site quickly and provides game habitat. Even clearcutting of aspen may be easier to accept by the public, because people understand how well it regenerates. We have already seen an increased interest in aspen management on the part of the National Forests and the state and county governments. High cost conversions to pines have declined in the last five years in the Lake States. This trend is likely to continue. Support is also coming from wildlife managers, who favor aspen for game management.

CONCLUSIONS

Aspen has grown in status from weed to "Queen of the North". There is much interest in aspen in both the resource and utilization fields. Understanding and innovation continue to increase. However, the future of aspen will depend on the sum of many individual decisions and actions on the part of governments, industry and individual landowners. Directing those individual actions will be beyond the control of any agency.

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ASPEN WOOD PRODUCTS UTILIZATION: IMPACT OF THE LAKE STATES COMPOSITES INDUSTRY

John A. Youngquist and Henry Spelter[1]

ABSTRACT.--The utilization of Lake States aspen for value-added products has increased dramatically in the last 15 to 18 years. This paper reviews aspen utilization for solid and composite wood products since 1970, discusses the forecasted future demand for wood-based composites, and reviews research that may influence future utilization of aspen in the Lake States.

INTRODUCTION

The proceedings for the first Aspen Symposium, which were published in 1972, included 26 papers, only two of which were on the subjects of trends and prospects for wood and fiber products. The program for the second symposium includes two plenary papers, eight technical session papers, and three technical poster displays, all on aspen products and utilization. Things have changed considerably in the intervening years. In 1972, Keays (1972) reported that the aspen harvest was roughly 50 percent of the allowable cut. He also predicted that within 30 years the allowable cut would probably double and that growth and use would be in close balance by the end of the century. These predictions have been proven accurate; however, the growth/cut balance was reached in only 17 years. In 1989, the concern is that the aspen cut is exceeding growth, and aspen supply will not be adequate to support the growing solid wood, composite, and paper industries in the Lake States region.

The Lake States of Michigan, Minnesota, and Wisconsin consist of a total of 122 million acres, 50 million acres (41%) of which are forested. Timberland represents 38 percent of the total land area in these three states, and the population is about 20 million. Moreover, more than 45 percent of the total U.S. and Canadian populations and total personal income are found within a 300- to 500-mile radius of the Lake States (Lake States Forestry Alliance 1987).

The purpose of this paper is to discuss the utilization of aspen for composite wood products in the Lake States by reviewing (1) the resource base available in the Lake States, (2) aspen utilization trends from 1965 to 1989, (3) aspen demand as opposed to availability, (4) the forecasted demand for aspen-based products, and (5) recent research that may affect aspen composite wood products in the near future.

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RESOURCE BASE IN LAKE STATES

As the demand for forest products of all types increases, pressures on the forest resource increase dramatically. The Lake States contain 45.9 million acres of timberland, which represents nearly 10 percent of all timberland in the United States (Lake States Forestry Alliance 1987). These resources are spread fairly uniformly across the Lake States: 13.6 million acres in Minnesota, 14.7 million acres in Wisconsin, and 17.4 million acres in Michigan. The species types of Lake States timber resources, which total almost 46 million acres, are shown in Figure 1 (Lake States Forestry Alliance 1987). The largest resource category is aspen-birch, followed by maple-beech-birch, fir-spruce-larch-cedar, and smaller amounts of other species.

ASPEN UTILIZATION

Aspen utilization has changed much over the past 25 years. Data compiled by the North Central and Northeastern experiment stations of the USDA Forest Service (Blyth and Smith 1988) show that aspen pulpwood production rose 150 percent between 1962 and 1986, from 1.6 to 4.0 million cords per year (Fig. 2). These figures understate the total use because they do not include aspen used by sawmills, veneer mills, specialty mills, and, lately, some waferboard mills.

Twenty-five years ago, most aspen was used for pulp, lumber, hardboard, and insulation board. Small volumes of higher grade logs were also used for veneer and miscellaneous items such as matches and tongue depressors. The advent of waferboard/oriented strandboard (OSB) has caused aspen utilization for solid-wood products to jump threefold since 1975 (Fig. 3) (U.S. Department of Commerce 1988, Anderson 1989, Anonymous 1988). In 1989, approximately 3.0 million cords of aspen will be used for solid-wood products.

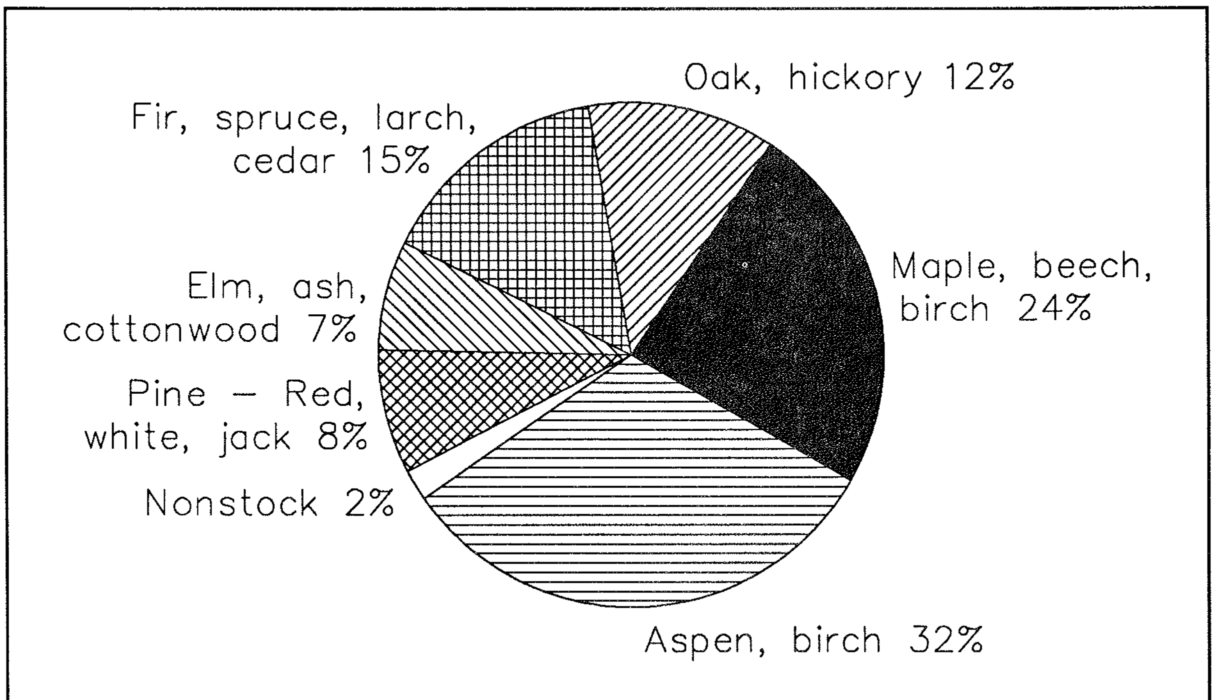

Figure 1.--Lake States timber resources by volume of timber type; 45,900,000 acres of timberland (10 percent of total U.S. timberland) (Lake States Forestry Alliance 1987).

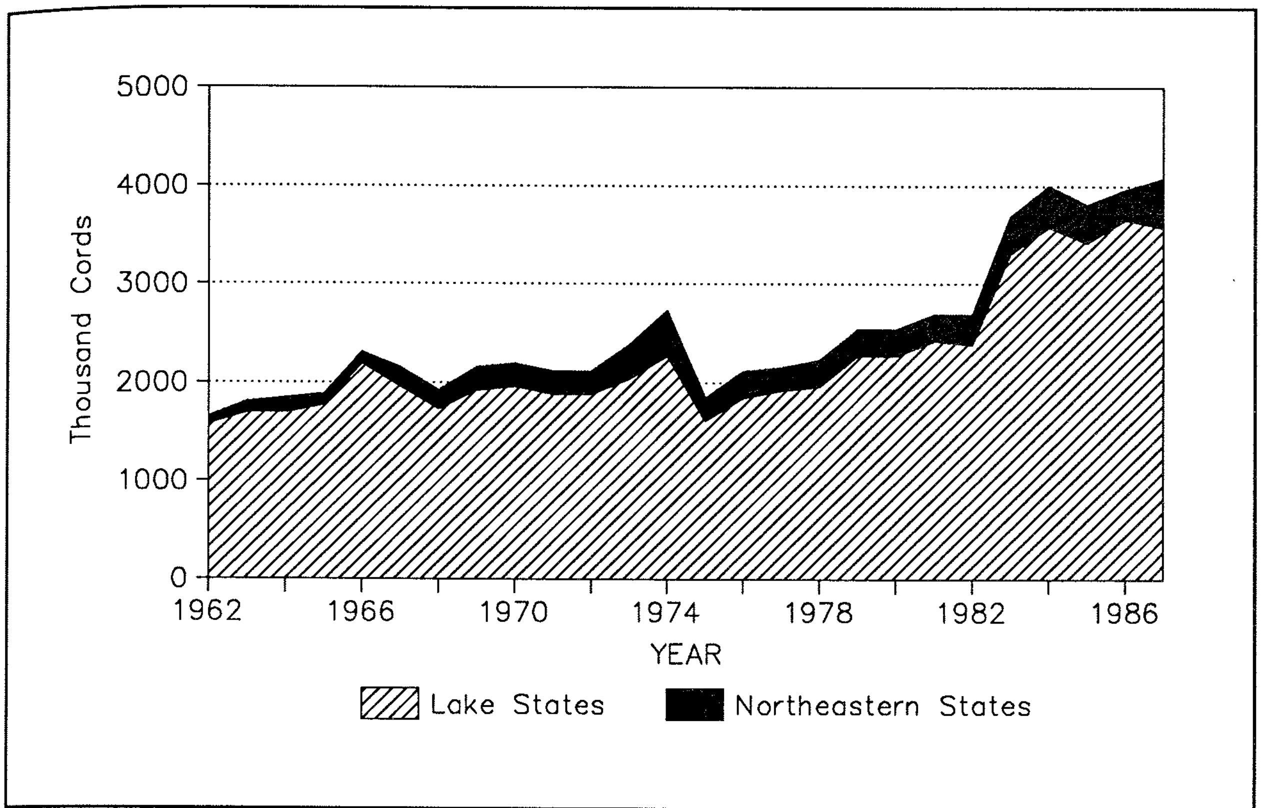

Figure 2.--Aspen pulpwood production in Northeastern United States (Blyth and Smith 1988).

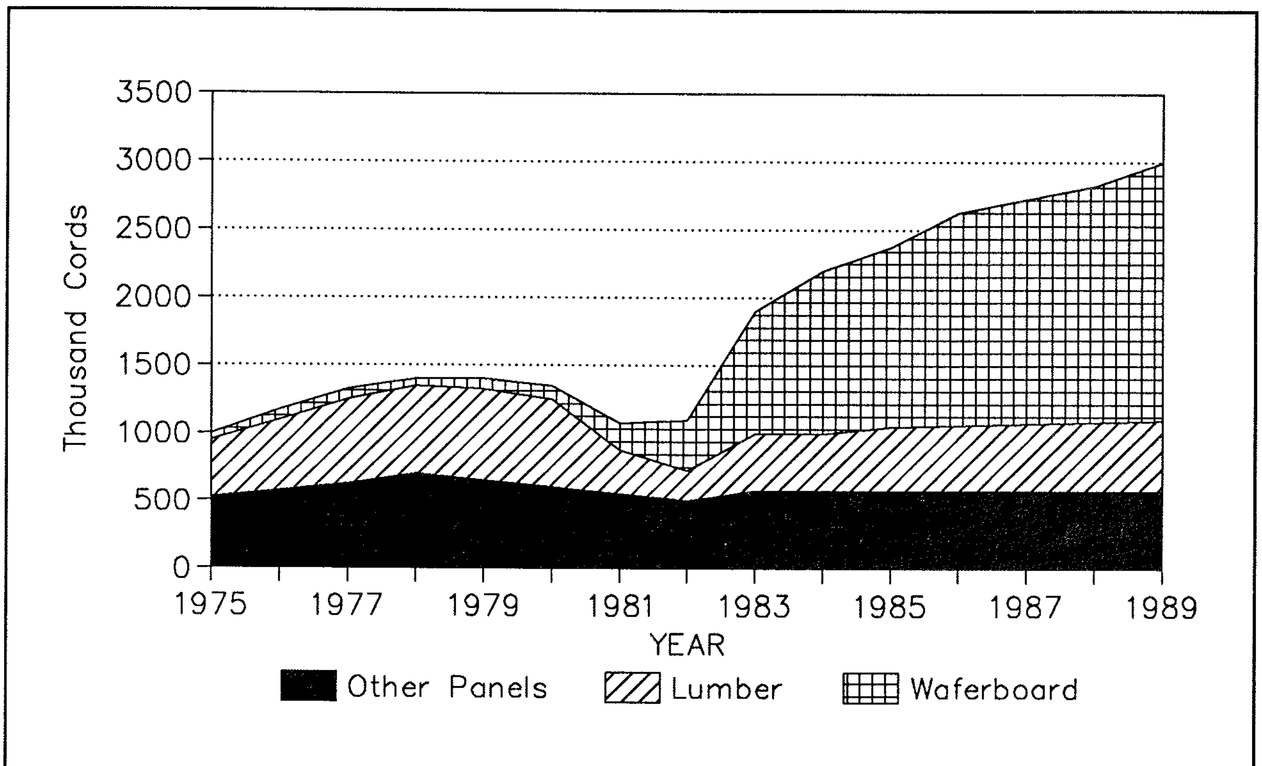

Figure 3.--Utilization of aspen solid-wood products (converted to cords) from 1975 to 1989 (Lake States Forestry Alliance 1987, U.S. Department of Commerce 1988, Anderson 1989).

In 1986, the most recent year for which all the data are available, waferboard/OSB accounted for approximately 59 percent of the solid-wood products total (Fig. 4). Waferboard is made from aspen almost exclusively, with only Northeastern mills adding other species (spruce-pine-fir) to their waferboard mix. Based on the production of new mills and mill expansions, the percentage of waferboard/OSB used should rise to around 63 percent in 1989. In the 1986 data, the next largest percentage of solid-wood products consists of lumber and hardwood (19 and 11%, respectively, of total products). Particleboard, which in the Lake States is made to a large extent from roundwood and chips rather than from mill wastes and residues, accounts for 4 percent of solid-wood products. Medium-density fiberboard, insulation board, and veneer accounts for the remaining 7 percent.

DEMAND OPPOSED TO AVAILABILITY

The growing stock of aspen is approximately 170 million cords. If we assume that the aspen growing cycle is 40 years, then the present use-rate of approximately 4 million cords per year is close to the sustainable yield level. The immediate outlook is for a continued increase in aspen demand. A collective look at Lake States capital investments in new or expanded wood-using facilities from 1979 to 1989 is presented in Table 1. This information is based on announced or projected capital investments by individual producing industries and includes $4.4 billion in facilities for pulp, paper, or paper products, $444 million for waferboard/OSB facilities, and lesser amounts for wood for energy, secondary manufacturing, sawmills, sheathing plants, and veneer (chopstick) facilities. These investments, which total over $5 billion, indicate that continued demand on the aspen resource will be high.

In some areas, harvests are presently below the allowable cut. In other areas, harvest is temporarily exceeding the allowable cut while overmature stands are being harvested. Forest managers generally feel, however, that by the early 1990s, when much of the overmature timber will be liquidated and the new or expanded wood-using facilities are in full operation, aspen supply will tighten in many areas of the Lake States.

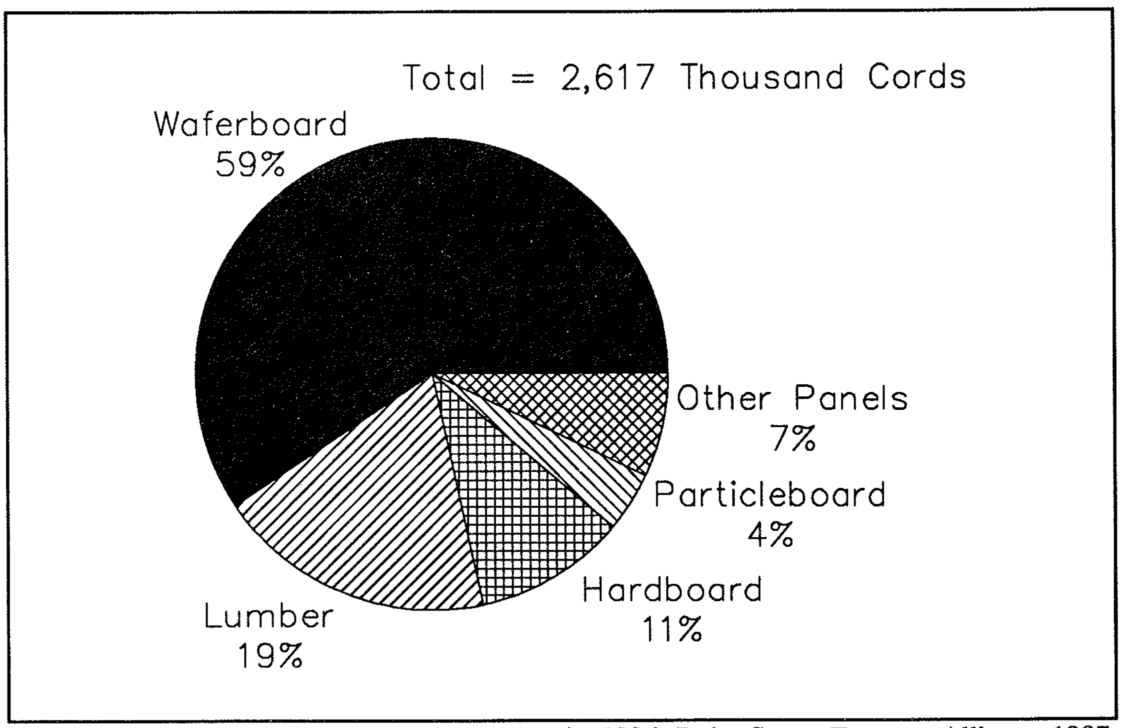

Figure 4.--Use of aspen solid-wood products in 1986 (Lake States Forestry Alliance 1987, U.S. Department of Commerce 1988, Anderson 1989).

Table 1.--Lake States investments in new or expanded wood-using facilities from 1979 to 1989.[1]

Product	Capital Investment (millions of dollars)	(percentage of total)
Pulp, paper, paper products	4,464	87.6
Waferboard, OSB	444	8.7
Wood for energy	93	1.8
Secondary manufacturing	68	1.3
Sawmill	15	0.3
Sheathing	12	0.2
Veneer (chopsticks)	6	0.1

Total	5,102	

[1]Lake States Forestry Alliance 1987.

One important consideration affecting availability is the price of aspen. In most areas, the delivered cost of aspen to mills ranges between $30 and $40 per cord. Stumpage prices average around $5/cord, with most sales between $4 and $10. Another approach for calculating the value of aspen is based on the residual value of the wood product after all manufacturing costs and normal operator overhead and profit are subtracted. Waferboard can be used as an example of such a calculation. Currently, waferboard selling prices are around $130 per thousand square feet (MSF) (3/8-in. basis). Mill labor costs are $10/MSF, energy $18/MSF, and adhesives $25/MSF. Capital depreciation expenses are about $12/MSF and overhead and profit are about $25/MSF. Harvesting and delivery expenses are about $30/cord or $26/MSF. Subtracting these costs leaves a residual value of $14/MSF or $16/cord, which is almost three times the current average stumpage rates for standing timber. This gap is the force that is attracting new or expanded mills into the region.

PROJECTED DEMAND FOR ASPEN-BASED PRODUCTS

According to the latest projection from the American Plywood Association (APA), the structural panel market will contract in 1989 (Anderson 1989). Over the long term, a moderate rebound will occur in the 1990s, but growth in demand for structural products will be slowed by the extended cyclical decline in demand for new homes resulting from decreasing population in the young, family-starting age group.

This modest outlook is bolstered for waferboard producers by the rapidly rising costs of western timber. Within the last 3 years, the doubling of western stumpage prices has placed panel mills in an unfavorable competitive condition. Accordingly, although overall panel demand may grow only moderately, waferboard demand should increase at a faster rate, and additional investment should take place in the Northeast aspen belt, from both expansion of old mills and installation of new mills.

LIKELY CHANGES IN THE LAKE STATES COMPOSITES INDUSTRY

In the following sections, only one or two specific examples of likely changes in the future are listed. In most instances, many more changes could be cited. By the time the next Aspen Symposium is held, additional changes will have certainly occurred.

ALTERNATIVES TO ASPEN FOR WAFERBOARDS

As the stands of pure aspen are being depleted, greater interest is arising in whether or not suitable waferboard/OSB products can be made by blending aspen with other plentiful species. Several studies have been made on this subject recently. A study by Gertjejansen and Hedquist (1982) indicated that a 10- to 15-percent substitution of paper birch for aspen resulted in little or no difference between aspen-birch and all-aspen boards. Panning and Gertjejansen (1985) reported that a mixture of 15 percent paper birch, 15 percent balsam poplar, and 70 percent aspen resulted in acceptable waferboard panels. Kuklewski et al. (1985) found that for both random and aligned boards, the properties of all red maple panels compared favorably with those of panels made totally from aspen. Other research studies have found that significant amounts of different species can be used in combination with aspen with no detrimental effects on the properties of the finished products. In general, these studies indicate that other species can be substituted for aspen, if necessary.

IMPROVEMENTS IN PROCESSING EFFICIENCY

Supplying wood products with consistent, predictable characteristics that provide good performance and reliability is essential for maintaining and improving the competitive position of the forest products industry, both domestically and internationally. Manufacturing products with the quality desired by the consumer at an investment return favorable to the producer is a key element to remaining competitive.

Differences among wood products are primarily related to differences in species, end-use specifications, and product quality. Lumber manufacturing and drying techniques are essentially the same for construction, industrial, and export lumber products. This is also true for panel manufacture and wood preservation methods. Consequently, manufacturing and quality control developments in the wood industry have a broad impact in many markets.

Product quality is of the utmost concern throughout the entire forest products industry. Improvement and consistency in product quality are needed in solid wood, wood fiber, and composite wood products for the construction and industrial markets. Export markets for wood products are especially sensitive to product quality.

Programs like the IMPROVE system now being developed at the Forest Products Laboratory (FPL) will continue to focus on increasing mill recovery and value potential by improving manufacturing efficiency. The IMPROVE system consists of eight major analysis programs: log processing, lumber manufacturing, lumber drying, dry end practices, veneer manufacturing, veneer drying, plywood manufacturing, and dry storage and shipping practices. The system will soon be expanded to include manufacturing operations in waferboard mills. Each of the programs consists of several routines that analyze various aspects of a given process. The routines can be used independently or in series, and they have been proven to improve quality and yield figures in actual mill trials (Lunstrum 1981).

INCREASED USE OF HARDWOOD FOR STRUCTURAL LUMBER

Until recently, structural lumber produced from hardwoods warped and twisted during drying. The Saw, Dry, and Rip (SDR) process eliminates this problem (Maeglin and Boone 1983, Maeglin 1985). As a result, structural grade lumber can now be manufactured from many low- to medium-density hardwoods. The most promising species are yellow-poplar, aspen, eastern cottonwood, sycamore, red alder, blackgum, paper birch, black willow, basswood, soft maple, sweetgum, and black cottonwood. In SDR, green logs are live sawn into 1-3/4-in. unedged planks called flitches. The flitches are dried to an average moisture content of 12 percent and then rip-sawed into studs. This process reduces warp by balancing stresses in flitches, restraining growth stress release, and reducing stress levels from drying. Drying at temperatures above 212°F also helps the studs remain straight. Stresses in the wood relax at this high temperature, and lignin, the bonding agent between fibers, becomes plastic and allows the wood fibers to slip past each other, minimizing the stress. As the wood dries, the lignin solidifies and holds the wood in an unstressed state.

The volume yields of SDR are comparable to conventional methods for manufacturing structural lumber. In addition, necessary equipment is readily available and existing mills may be easily adapted to the SDR process. The SDR process has the potential for making hardwood structural lumber a standard commodity and for relieving the pressure on the diminishing softwood resources in the West. This process should also benefit the Eastern states, particularly because most residential and light-frame building occurs in the East and low- to medium-density hardwoods flourish there.

INCREASED USE OF COMPOSITE LUMBER

Laminated veneer lumber (LVL) consists of parallel laminated veneer panels ripped into lumber widths. Researched extensively since the early 1970s, this veneer processing technology combines existing plywood manufacturing methods with new laminating techniques to develop a product with greater uniformity and predictability than solid lumber (Youngquist and Bryant 1979, Laufenberg 1983, Youngquist et al. 1984). Tests have shown that the strength of LVL specimens compares favorably with that of most high-strength lumber grades. As a result, LVL offers a viable alternative to structural lumber.

Most operations that produce LVL for structural use are similar to plywood operations. Veneer is rotary peeled, dried, spread with adhesive, assembled in the desired configuration, pressed either in conventional plywood presses or on a continuous or step basis, and then ripped to width. Modifications in the conventional process, such as continuous pressing, have been developed primarily to meet the performance requirements for specific end-products.

The furniture industry has used LVL for many years to produce curved furniture parts (Hoover et al. 1980). Recently, more LVL has appeared in the marketplace because high-quality, solid-sawn structural lumber has become more scarce and expensive. The markets for LVL appear limitless--it can be used for truss components, I-beams, bench seats, truck decking, door/window headers, scaffold planking, ladder stock, bridge stringers, and other interior and exterior applications.

Products made from LVL have several advantages over solid-sawn lumber products. For example, warping and checking are practically eliminated because the veneer is dried before gluing. Also, because laminating disperses wood defects, most mechanical properties will be more uniform than the same properties in solid-sawn wood of comparable quality. The yield of LVL products is 15 to 30 percent greater than that of solid-sawn products. In addition, preservative treatment of some species is more effective on LVL materials.

Over the last 15 years, the FPL has developed an extensive LVL database that focuses on raw material options, processing alternatives, product performance levels, system and product economics, and alternative marketing opportunities. This database has contributed significantly to the work of the American Society of Testing and Materials (ASTM). An ASTM task group is working on a general format for evaluating structural lumber substitutes and has developed two new U.S. standards. The first standard, developed by the American Institute of Timber Construction (AITC), provides for LVL as a substitute for tension laminates in glued laminated beams. The other standard, which is proposed by the APA, will use performance ratings and will provide for trademarking based on the mechanical capabilities of the product. Thus, the future for the LVL industry looks promising.

The importance of LVL products is expected to grow as the wood industry uses more small-diameter trees. The versatility of LVL is a good example of how our renewable forest resources can provide a broad array of structurally efficient products to benefit manufacturers and consumers alike.

LOW DENSITY, HIGH STRENGTH PANEL PRODUCTS

A steam injection process has been developed (Geimer 1982, 1983) that reduces press times for flakeboard, particleboard, and medium-density fiberboard production. Wood flakes are initially coated with a resin and formed into a mat. The mat is then loaded into a press and a burst of saturated steam is injected through perforated platens. Within several seconds, the temperature in the board center rises to approximately 220°F. As the board is compacted, the internal pressure increases, allowing the temperature in the board center to rise to between 280°F and 315°F. This high temperature accelerates the resin cure. Several seconds after the steaming period, the temperature falls to about 225°F and stabilizes there for the remainder of the press cycle. A computer used to control the steam injection schedule also monitors the rapidly changing press operation. It records time, temperature, and several other variables in 0.5-second increments.

Tests conducted at the FPL indicate that press time for a 0.5-in.-thick board can be reduced from 4.5 minutes to about 90 seconds. Also, the 45 minutes needed to conventionally press a 2-in.-thick board can be reduced to less than 5 minutes with steam injection.

This new steam injection process uses smaller equipment and less energy than conventional pressing methods. Steam injection also offers the possibility of incorporating additives that increase durability and fire resistance of the board.

STRUCTURAL PAPER PRODUCTS

Researchers at the FPL have developed a structural fiber concept called FPL Spaceboard (Setterholm 1985). To make the three-dimensional structural board, fibers are press dried against rubber molds with waffle-like configurations to produce two symmetrical halves. An adhesive is then used to bond the two halves, creating numerous small geometric-shaped cells in the board center. Using this technique, FPL Spaceboard can be made as a laminate or sandwich, thin enough for strong light-weight corrugated containers or thick enough for wall sections. The result is a fiber composite structural material that is strong in every direction. Laboratory tests show that FPL Spaceboard is between 30 and 200 percent stronger than conventional corrugated fiberboard. The strength of Spaceboard is due to the special configuration of the core and the superior strength of the press-dry method that molds the core and facing together.

With further refinement, FPL Spaceboard can provide the wet strength and dimensional stability necessary to build highly engineered structures as well as significantly improved fiberboard containers. The superior performance parameters of Spaceboard are as follows:

1. Improved strength-weight characteristics of press-dried fiber facings

2. Unequalled versatility in mechanical design variables--sheet size, cell size, sandwich thickness, and core density

3. Adaptability to a wide range of raw materials

The FPL Spaceboard is a concept in structural fiber construction and, as such, its full potential for application and the economic payoff are yet to be determined. Thus far, FPL scientists have made only a limited number of experimental samples. However, because of its many design and processing attributes, FPL Spaceboard has good potential for use in commercial and residential construction, mobile homes, recreational vehicles, packaging containers, and wall and ceiling panels.

WOOD STABILIZATION TECHNOLOGIES

A world-wide team of scientists, led by FPL Research Chemist Roger Rowell, is currently studying the chemical modification of wood and reconstituted wood products (Rowell et al. 1986). Studies on improving wood properties through chemistry began at the FPL in the late 1930s. They were expanded in 1972, with the advent of new technology, improved analytical instrumentation, and environmental concerns for toxic methods of wood protection.

Rowell and others established that chemical modification of solid wood by epoxidation or acetylation greatly improved dimensional stability. The mechanism of improved stability is based on bonding chemicals to the cell wall polymers resulting in bulking. Chemically modified wood swells to near its green dimensions, so little additional swelling occurs when the modified wood is wetted. The swelling of wood modified with anhydrides, epoxides, and isocyanates has been reduced as much as 65 to 75 percent at bonded chemical weight gains of 20 to 30 percent. Biological resistance is achieved as well when the bonded chemical is distributed in the polymers, which are available to attacking marine organisms, termites, and decay fungi.

In tests using Southern Pine, aspen and Douglas-fir flakes, acetylation reduced liquid water uptake by 50 percent and reduced thickness swelling by 85 percent in flakeboards made from the acetylated flakes. Repeated water soaking/ovendrying tests showed that both epoxidation and acetylation decreased reversible and irreversible (springback) swelling in flakeboard as compared to untreated boards. Springback is caused by the release of residual compressive stresses imparted to reconstituted boards during the pressing process.

The FPL modification methods developed for solid wood can be applied directly to reconstituted wood products with confidence because standard operating procedures in the composite panel industry are exactly those required for successful chemical modification. The requisites are dry wood materials, spray chemical addition for maximum distribution, small sample size for good distribution, and high temperature and pressure in product formation.

Particleboards made from acetylated chips also show greatly improved resistance to tunneling bacteria and brown-, white-, and soft-rot decay fungi as well as decreased hygroscopicity. The greatest potential for chemical modification appears to be in dimensionally stable reconstituted wood products, whose commercial application could be very wide. This and other ongoing research brings FPL scientists together with scientists in many other countries, including China, Sweden, Poland, the United Kingdom, Denmark, France, Germany, New Zealand, and Japan, in studies on acetylation and other chemical modification techniques.

WOOD/NONWOOD COMPOSITES

Combining wood with other materials to form new composites presents many opportunities for development in the forest products industry (Youngquist and Rowell in press). This is a very active research field; many new ideas are being examined. Many species of wood, including aspen, are being combined with other biomass materials, metals, plastics, glass, and synthetic fibers, and the properties of these new composites are under investigation. The new composites will be introduced on the market as low-cost substitutes for more costly materials or in applications where specific performance attributes are required. Through modification of either the wood or the nonwood part of the product or both parts, the new composites can have performance characteristics that are superior to products made from either component alone.

Technological innovation and new product development are vital to maintaining industrial competitiveness and increasing the efficiency of the manufacturing process. This in turn leads to economic growth and enhances the wealth of the nation. The forest sector of the economy particularly is influenced by the development of new materials such as plastics, metals, cement products, ceramics, and composite materials, which have displaced or have the potential to displace many wood-based products. In many nonwood industries, manufacturing process efficiency is increased by improvements in process systems and the amenability of metals and plastics to high-speed automated machines. Some processing concepts can effectively utilize wood in one form or another and are very amenable to high-speed processing (Marcin 1988).

One current processing option for using wood combined with plastics relies on extrusion or injection molding technology, in which thermoplastic resins are thoroughly mixed with finely ground wood particles or flour. This mixture is then forced out through a die to form a sheet product, which can be processed in a secondary manufacturing operation into a number of molded or corrugated shaped sections. When preparing fiber-reinforced composites using extrusion techniques, the amount of compounding that takes place prior to product formation must be optimized.

In another processing option, a high percentage of natural fibers are blended with synthetic thermoplastic or thermosetting fibers to form a nonwoven mat, which can be handled in roll form and which lends itself to automated handling and processing in subsequent operations. This mat can be made from a wide mix of synthetic and natural fibers resulting in products with properties suitable for the end-use intended. Subsequent processing options can then be used to fabricate flat sheet or panel products or deep-drawn molded configurations.

Because of the increased processing flexibility inherent in both the extrusion and nonwoven technologies, a host of new natural-synthetic fiber products can be made. These products can be produced in various thicknesses, from a thin material of 3 mm to structural panels up to several centimeters thick. A great variety of applications are possible because of the many alternative configurations of the product. The three major classifications of potential products are packaging products, manufactured products, and corrugated or sandwich-type configurations for floor, wall, and/or roof components.

CONCLUDING REMARKS

Technological advances have greatly expanded the value of aspen and its range of possible uses. The immediate impetus for the new-found importance of aspen has been the rapid expansion of the waferboard/oriented strandboard industry in the Great Lakes States and Northeast. We expect further growth in this sector along with growth in other reconstituted wood products such as oriented strand lumber or laminated veneer lumber. However, the sharp rise in the demand for aspen has resulted in a concern about the adequacy of future supply; data indicate that aspen use is nearing sustainable supplies. At the same time, research has indicated that partial substitution of different underutilized species for aspen can extend the fiber supply. The increasing demand for wood products, the decrease in supply from traditional wood-supplying regions, and the development of new potential markets through research on wood/nonwood composites, structural use of hardwoods, and composite lumber will augment the importance and value of aspen and other hardwood species in the Lake States and the Northeast.

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CONSTRUCTION OF FOREST GROWTH MODELS BASED ON PHYSIOLOGICAL PRINCIPLES

Thomas E. Burk, Risto Sievanen, and Alan R. Ek[1]

ABSTRACT.--Basic structures for management-oriented forest growth models have changed little over the last several decades. If additional progress is to be made in the prediction of forest growth, especially under a potentially changing environment, new modeling approaches must be sought. We discuss the use of physiological principles for construction of forest growth models. An example of such a model is presented for aspen. Extensions necessary for modeling at the tree level are discussed. Key components and methodological advances requisite to making such models practical for forest management decision making are outlined.

WHERE WE'VE BEEN

The utility of forest growth models for rational management decision making is indisputable. Equivalents of the major types of forest growth models in use today (cf. Ek and Monserud 1981 for a review) date back several decades, perhaps to more than two centuries in some cases. Today's whole stand models have roots in the traditional normal yield tables; Assmann (1970) provided a reference to work dating 1795 on such tables. Based on the assumption of a gamma distribution, Schnur (1937) used mean and standard deviation of diameter at breast height (DBH) to model size class yields of upland oaks, an approach now commonly referred to as diameter distribution growth modeling. The methods of stand table projection has surely been an important component of the forester's toolbox for many years; Chapman (1924) outlined three such approaches. Individual tree growth models of today are elaborations on the stand table projection idea.

Advances in forest growth modeling in the past two decades have centered on applying more rigorous computational, mainly statistical, techniques to data collected. This research has resulted in models that better fit observed data. Recently, emphasis has been placed on an improved accounting of the error structure implicit in forest growth measurement data. More readily available computing power has also allowed researchers increased flexibility in model specification. These advances initially resulted in substantial improvements in our capability to predict growth; most notable was the elimination of the need to assume some "approach toward normality," an obvious hindrance for a model attempting to predict for differing management actions. The degree of improvement within the last decade has been less impressive.

In retrospect it appears biometricians have been more concerned with model specification and calibration than model formulation. The basic principles from which forest growth models have been derived have changed little. An exception might be the biomathematical approach put forth by Pienaar

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and Turnbull (1973) and best illustrated by Farnum et al. (1986) and Harrison and Daniels (1988). In these models primary emphasis is placed on adherence to "first principles" of forest growth. Model formulation is less dependent on data and thus the resulting model is more extensible.

During the same period a more physiologically based approach to predicting forest growth has been adopted by some. Instead of modeling the result of growth, dimensional change, emphasis has been placed on understanding the processes of growth (light interception, photosynthesis, respiration, transpiration, water and nutrient uptake, etc.) and modeling those processes. Such work in forestry developed from that done with agricultural crops (cf. Promnitz and Rose 1974). This is surely a vastly different approach to model formulation and seemingly has much potential. However, due to the complexity of the growth process, progress has been slow and the sentiments of many forest growth modelers may be reflected in the following quote from a recent growth modeling conference (Chappell and Maguire 1987):

> There are those of us who although we think they're sweet and lovable people, don't think process-based modelers are going to get anywhere. It is open-ended physiological research ... I have never found the people that did it [process modeling] to produce a valuable result.

Much effort in so-called process modeling has been expended on explanation; less effort has been devoted to predictive ability, the key to practical utility of any forest growth model. Early examples of such models have also been criticized for concentrating solely on total biomass yields.

Publication of the JABOWA model by Botkin et al. (1972) illustrated that there may be a useful middle ground between the more traditional approach to forest growth modeling and that approach based on physiological principles. Although the output from JABOWA is DBH increment, the components are driven by environmental inputs and assumptions about physiological processes. JABOWA derivatives have been used to simulate long-term successional patterns of forests (cf. Dale et al. 1985) though its success in predicting the growth of individual forest stands has not been well documented (Ek et al. 1984). Two problems with the JABOWA approach are the lack of application of rigorous calibration procedures and the use of forcing functions that attempt to account for the direct effect of environmental factors (light, moisture, nutrients) on DBH increment; surely, the direct effect of such factors is on growth processes. Further, the dependence of such functions on extensive data bases for calibration offers little advantage over the more traditional approach.

STRUCTURE OF FOREST GROWTH MODELS BASED ON PHYSIOLOGICAL PRINCIPLES

An excellent schematic of the structure of a physiologically-based forest growth model was given by Mohren (1987, p. 20). Most commonly the primary processes considered are photosynthesis and growth and maintenance respiration. Photosynthesis is affected by weather parameters such as incident radiation and temperature, soil parameters such as moisture and nutrient availability, and species specific parameters or functions such as how photosynthesis rate depends on incident radiation. Maintenance respiration of living tissue and growth respiration will likewise be affected by species specific and weather parameters. Net growth at any instant is allocated to compartments (foliage, branches, roots, stems) which affects the principle feedback mechanism in physiologically-based forest growth models: the influence of stand structure on prevailing environment. Mathematically, the structure of a physiologically-based forest growth model can be represented by the system of equations

$$W_i(k+1) = W_i(k) + (1 + r_{gi}(k))^{-1}(\lambda_i(k)P(k) - R_{mi}(k)) - S_i(k)$$

where W is dry weight of a compartment, r_g is growth respiration rate, l is an allocation coefficient, P is gross photosynthesis (dry weight), R_m is maintenance respiration (dry weight), S is litter loss (dry weight), i labels compartment, and k labels time.

It should be obvious that this structure is quite different from that of the more traditional forest growth models or of JABOWA type models. Recall for the latter models, forcing functions for important environmental parameters dealt directly with dimensional change. In physiologically-based forest growth models the relevant forcing functions are applied to the growth processes themselves. Sievanen (1983) gives examples for the influence of temperature on rate of photosynthesis and maintenance respiration rate. Nilsson and Eckersten (1983) presented a model where nitrogen concentration directly affected rate of photosynthesis.

Parameters and forcing functions for physiologically-based forest growth models are in some sense more basic and certainly more interpretable and extensible than those of more traditional models. While this is an obvious advantage, at least two implicit challenges arise; 1) physiologically-based forest growth models tend to have many more parameters than state variables and 2) simplicity of structure necessitates a greater dependency on dynamical parameters and forcing functions. These are discussed later.

Similar to any forest growth model, several important considerations arise when developing and calibrating a physiologically-based forest growth model: What should the modeling unit be? What should be the resolution of each model component? What should the time step be? What procedure / response should be used for calibration? Physiologically-based models can be envisioned at the leaf, tree, or stand level. As with more traditional models, a tree based approach has several advantages including emphasis on the smallest growth unit of interest and an allowance for more straightforward treatment of within stand dynamics. Disadvantages of a tree based approach are the obvious added complexities required for all model components, especially if a below-ground component is involved. Some questions may require more detail than is provided by a tree based approach; the idea of "autonomous physiological units" (Isebrands et al. 1989) would suggest using stem and branch units as the modeling basis. Once a modeling unit is chosen, consideration must be given to component resolution. To take an example, light interception can be handled by developing a very complex component requiring detailed information or assumptions regarding canopy structure. Or, simpler hypotheses (Beer's Law in this case) can be augmented by empirically or theoretically determined forcing functions (Kellomaki et al. 1985). Component resolution has important consequences in terms of model usage requirements. If a detailed below-ground component is included in the model, separate moisture and nutrient models would most likely be needed as well. Given the ready availability of powerful personal computers, time step requirements are no longer a serious limitation for any forest growth model. However, for efficiency reasons the longest time step reasonable should be preferable. Traditional forest growth models commonly utilize a time step of one year; since environmental impacts have differing consequences at different times in the growing season, such a time step may not be appropriate for physiologically-based models. Different model components may have different time step requirements. Since any growth model is ultimately a means of estimating an integral, integration algorithms have promise for selection of optimal time steps. The ultimate goal of any forest growth model is prediction. To meet this goal, model parameters must be calibrated by some objective means using relevant data. Researchers have only recently come to this realization in regards to physiologically-based models; Sievanen et al. (1988b) illustrate using a strict statistical approach while Makela (1988) used a Monte Carlo approach. Possibly more important than the specific approach is the need for the model to predict in terms of a measurable attribute such as tree DBH or stand basal area on a periodic basis.

A WHOLE STAND MODEL FOR ASPEN

Several authors have applied the ideas of physiologically-based forest growth modeling to the development of stand level models for species grown in pure, even-aged conditions (cf. McMurtrie and Wolf 1983, Mohren et al. 1984). Here we use those ideas to develop such a model for pure stands of aspen and calibrate the model using yield table data for one extreme site class (computer code for model implementation may be requested). We then attempt to predict for the other extreme site class by manipulating a minimum parameter set.

The model developed has a time step of one year and generally follows the system of equations presented in the last section. The basic approach taken was to compute a potential production rate for an average year which would in turn be reduced by leaf area index (LAI), a light extinction coefficient (K), and degree of crown closure (CC) for any year; K and CC were determined using time dependent empirical forcing functions. Allocation to stems, foliage, branches, and roots were assumed constant throughout the growth period as were maintenance respiration rates for each component and an overall growth respiration rate. Respiring stem biomass was assumed to be that accumulated within the previous eight growing seasons. Foliage biomass was converted to foliage area by assuming a constant specific leaf area. Litter loss rates for foliage and roots were assumed constant over the growth period while a time dependent empirical forcing function drove litter loss rate for stems and branches.

All parameters in the model (basic parameters such as the allocation coefficients as well as parameters of the time dependent empirical forcing functions) were assigned an interval of "most likely values" by search of the literature and subjective reasoning. The model was then "fit" by a Monte Carlo approach where random deviates from each interval were generated, the growth model run for the entire growth period using those parameters, and squared prediction error computed. The Monte Carlo trial with minimum error was selected as "best fit"; 2000 trials were examined.

Goudriaan and van Laar (1978) have illustrated methodology to compute potential gross CO_2 assimilation of closed leaf canopies. Using maximum photosynthesis rates of 10 to 20 kg CO_2 ha^{-1} h^{-1}, LAIs of 5 to 10, average percent sunshines of 30, 40, 50, 60, and 70, and a growing season of April 15 to October 1 at 48 degrees of latitude gave predicted potential productivities of 50 to 100 metric tons CO_2 per hectare per growing season. This defined an interval of most likely values (Table 1). CO_2 production was converted to dry weight by dividing by 1.74. Realized assimilation was potential reduced by the function (after Mohren et al. 1984)

$$CC\ (1.0 - \exp(-K\ LAI))$$

Most likely values for specific leaf area, above-ground allocation, and age one biomass were approximated from the studies of Pollard (1972), Koerper and Richardson (1980), and Ek and Brodie (1975). Information on other basic parameters was obtained from the best source available, though subjective judgement also played a role (Table 1).

K was assumed to be at a constant maximum between age 2 and age 15 and then decrease linearly to a low at age 80; the ranges for maximum and minimum were specified based on reports for other tree species (Table 1). CC was assumed to follow a power function up to an age where it would reach and be maintained at 1.0. The power function was specified by the ages at which CC=1.0 and CC=0.5 (Table 1). Stem and branch loss rates were assumed to decline in a negative exponential fashion up to crown closure after which a constant loss rate was assumed (Table 1).

Results of "fitting" the model to Schlaegel's (1971) high site (80 feet, base age 50; 60 square feet of basal area at age 15) yield tables appear in Table 1 and Figure 1 (dry weights were converted to volume measure by assuming 0.37 tons m^{-3}). The model seems capable of reproducing the yield trend, though it tends to be more sigmoidal in shape. It is unknown which is actually correct though the result may imply maintenance respiration needs further treatment. Recent work by Bunce (1989) suggests that an assumption of a constant ratio between maintenance respiration rate and photosynthesis may be preferred over one of a constant maintenance respiration rate. It has also been suggested that accounting for different maintenance respiration rates for different age classes of respiring material may have a similar effect (personal communication, Dr. E.I. Sucoff, University of Minnesota). Fitted values for parameters generally seem reasonable and are in the neighborhood of those used by Mohren et al. (1984) at a similar latitude but with a different species. The exceptions are root allocation, maintenance respiration, and litter loss which are too high and age of crown closure which is too high; these may point to model deficiencies though the former may simply be a consequence of the calibration data being limited to above-ground.

Table 1.--Model parameters and fitting results.

Parameter[1]	Most Likely Range Min	Max	Fitted Value[2]	Units
		----Basic Model Parameters---		
PP	29.0	57.0	42.3	tons dry weight ha^{-1} yr^{-1}
SLA	0.95	1.1	0.973	ha ton^{-1}
r_g	0.2	0.4	0.3	---
λ (stem)	0.15	0.35	0.24	---
λ (foliage)	0.2	0.35	0.3	---
λ (branch)	---	---	0.1	---
r_m (stem)	0.01	0.05	0.012	---
r_m (foliage)	0.6	0.9	0.72	---
r_m (branch)	---	---	0.05	---
r_m (root)	---	---	0.13	---
l (stem)	0.01	0.04	0.029[3]	---
l (foliage)	0.1	0.5	0.18	---
l (branch)	---	---	0.05[3]	---
l (root)	---	---	0.2	---
W_{stem} (1)	0.7	1.5	1.4	tons dry weight ha^{-1}
$W_{foliage}$ (1)	0.6	1.2	0.9	tons dry weight ha^{-1}
W_{root} (1)	---	---	0.5	tons dry weight ha^{-1}
		---Forcing Function Parameters---		
K_{15}	0.75	0.85	0.82	---
K_{80}	0.4	0.75	0.73	---
$ACC_{1.0}$	20	40	35	years
$ACC_{0.5}$	5	15	6	years

[1]PP = potential photosynthetic production, SLA = specific leaf area, r_g = growth respiration rate, λ = allocation coefficient, r_m = maintenance respiration rate, l = litter loss rate, W (1) = initial weight, K_i = light extinction at age i, ACC_i = age at which crown closure is i*100 percent.
[2]Fitted to Schlaegel's (1971) high site yields (see text).
[3]Value reached after crown closure (see text).

Significantly, Schlaegel's low site (60 feet, base age 50; 50 square feet of basal area at age 15) yields could be reproduced by changing only four parameters: allocations to stems and foliage were reduced to 0.16 and 0.23, respectively (root allocation increased accordingly) and the ages defining the crown closure forcing function increased to 38 and 8. These changes are all readily justifiable. Although not shown, results for a medium site where similarly encouraging.

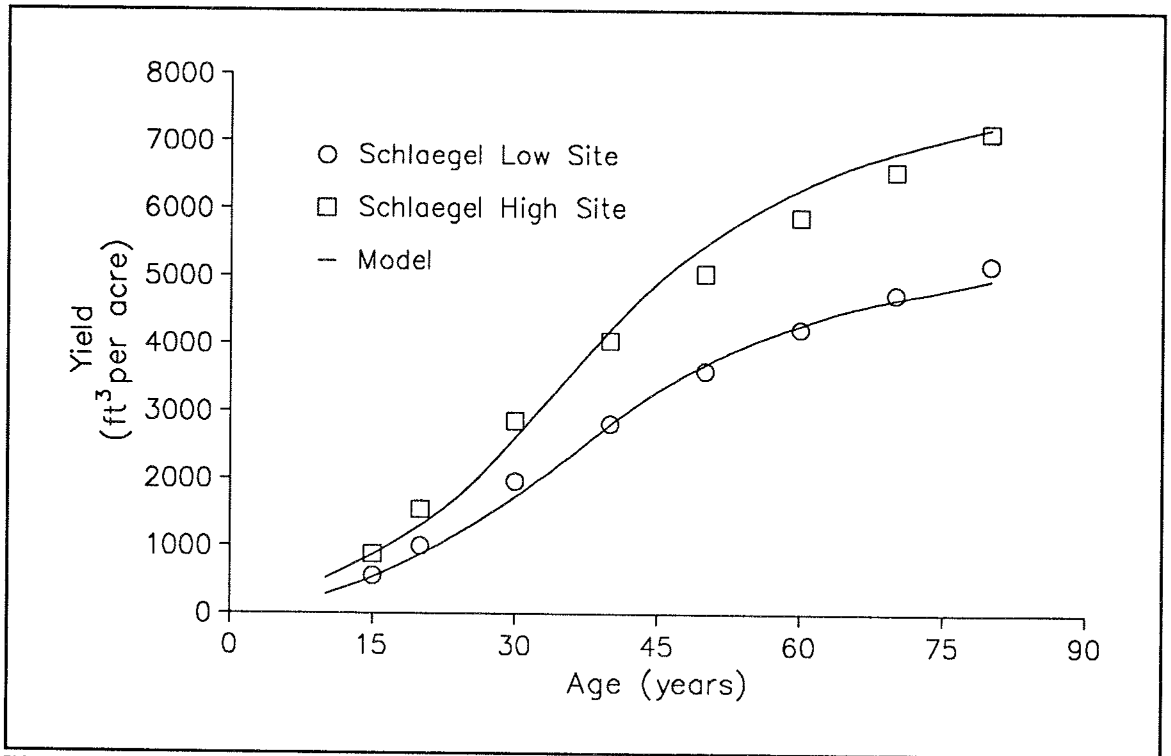

Figure 1.--Model fits to published yield table data.

EXTENSIONS TO THE INDIVIDUAL TREE LEVEL

Many forest management decisions require information more detailed than whole stand yields; the differentiation between stems that takes place as the stand develops is often of high interest. A forest growth model where the modeling unit is the individual tree provides the necessary degree of detail. Makela and Hari (1986), West (1987), Oker-Blom et al. (1988), and Sievanen et al. (1988a) are illustrative of various approaches to developing such physiologically-based models.

Sievanen et al. (1988a) show that it is possible to develop a physiologically-based individual tree model that reduces to one equation for individual tree increment. Such a model can thus be fit and used much like a traditional individual tree model. Most such models will have a high level structure similar to the whole stand model described above. However, in contrast to whole stand models, single tree light interception must be accounted for in individual tree models. This is best handled by computing and keeping track of each tree's (in a representative tree list) contribution to the canopy as determined by its height and crown ratio. Distance-dependent models may show a clearer advantage here than has been previously found since they will no longer be developed around ad hoc competition indices. The other component implicitly required in such models is a means of recovering dimensional characteristics such as tree DBH and tree height. Equations relating mass to dimension at the tree level must therefore be added to the model. While this appears a rather straightforward step it has important implications for model calibration.

WHERE WE'RE GOING

Sievanen and Burk (1989) have recently discussed the applicability of physiologically-based growth models for forest management decision making. There are a number of issues concerning these models that require further study. Among these are how to handle mortality, how best to calibrate, the role of complex models, and whether expert systems will play a part.

No current physiologically-based forest growth model contains an adequately tested mortality component. Tree based models are to be preferred in this respect as it is the individual tree that dies, not some artificial part of the stand. Most tree based models kill off trees in increasing proportions as net production slows. The highly stochastic nature of mortality may point to the need for a more statistical treatment of this component. Physiologically-based and traditional models may come together at this point.

Objective calibration is a necessity for any model whose primary use is prediction. Physiologically -based forest growth models typically have many more parameters than state variables which makes their calibration quite difficult. Sievanen et al. (1988b) were only able to reliably estimate six of 14 model parameters by standard statistical means. The Monte Carlo approach used for the whole stand model above provides an alternative though, for very complex models, such an approach is inefficient. More work must be done on this critical issue.

The complex leaf based models being developed by some researchers (cf. Isebrands et al. 1989) will not soon have high utility for typical forest management decision making situations. Their utility lies in answering questions related to what simplifications can be made without loss of explanatory and predictive power. For example it would be difficult to evaluate differing time step lengths without a baseline which utilized a suitably short time step. Or, the importance of accounting for precise foliage distribution and angle patterns can only be answered if models which account for these are available. At the same time these highly detailed models require much development so that entire rotations can be simulated and management treatment effects can be reliably evaluated. Quality, concurrent tree growth and weather data will be required.

Future development of physiologically-based forest growth models will require greater interaction between biometricians and physiologists. Since much of the information that physiologists have acquired is not in a form that readily lends itself to quantitative modeling, expert systems may initially play an important role in this interplay. As this relationship matures, more quantitative modeling should be possible. However, some control systems may ultimately best be handled as information management problems (cf. Isebrands et al. 1989).

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ASPEN STAND DEVELOPMENT IN BELTRAMI COUNTY, MINNESOTA

Gregg P. Hove and Charles R. Blinn[1]

ABSTRACT.-- Forest managers are concerned about stand development following harvest. To make management financially attractive, harvest revenues must at least equal costs, when all are properly adjusted to take timing differences into account. An observational study was conducted to evaluate aspen stand development and economics on lands managed by the Beltrami County Land Department. Regeneration was measured in 70 stands aged 2 to 9. Results indicate that stand development, as measured by the number of preferred trees per acre and average height of the potential crop trees, was related to factors such as the density of residual trees on the site, season of harvest, and the basal area of aspen in the parent stand. Revenues required to provide a 3.5 percent real rate of return rose at an increasing rate with rotation age.

INTRODUCTION

Not that many years ago, the aspen tree (Populus tremuloides Michx.), was thought of as an unwanted species, that interfered with the reforestation of other more important trees. However, this is not the case today, especially in the Lake States where recent technology has resulted in new uses for aspen. Beltrami county, located in north central Minnesota, is now experiencing an increased demand for aspen, mainly because its geographic location serves as a procurement area for several wood industry businesses. Therefore, the Beltrami County Land Department (Land Department) has an opportunity to provide local mills with aspen pulpwood as they attempt to achieve a sustained supply of timber for the future. In the process of supplying this raw material, the Land Department acts as a "profit center" (within the county system) with an end goal of maximizing profits over costs, thereby reducing the tax load for county residents. Because of these management and economic concerns, the Land Department expressed an interest in an analysis of aspen stand development and economics to evaluate the effectiveness of their aspen management activities. An observational study, funded by the Legislative Commission on Minnesota's Resources (LCMR) and the University of Minnesota, was conducted to provide answers to these aspen management concerns.

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STAND DEVELOPMENT ANALYSIS

Data Collection

Aspen stands to be evaluated were first identified and then field visited. The types of data collected included stand history and field data.

Stand History.--An initial list of candidate stands was obtained from the Land Department's computerized Phase II inventory. Stands were classified according to harvest season, (growing season = May 1 to August 31, dormant season = September 1 to April 30). Stands were deleted from this initial list for the following reasons:

a. Lack of accurate stand history data - without this baseline data, it would not be possible to evaluate stand development.

b. Stand harvest extended across harvest seasons - harvests of this type could result in an uneven age distribution within the stand.

c. One-year-old stands - these stands could have high variability in stem number because of ingrowth and outgrowth that may occur during that period (Brinkman and Roe 1975; Ek and Brodie 1975).

Stand management activity data was collected from Land Department records (Table 1). A matrix was developed plotting harvest season for each stand against current stand age to synthesize the data. Stands to be surveyed were randomly selected from this matrix by drawing numbers from a table of random digits (Avery and Burkhart 1983). A maximum of 70 stands between the ages of 2 and 9 was set. An upper age limit of 9 years was used because of a lack of historical information.

Field Data.--Twenty-six growing season stands and forty-four dormant season stands were surveyed after September 1, 1988. Emphasis during the field data collection was in looking for differences between treatment and site conditions. Therefore, a relatively large number of stands were examined with few plots per stand.

Table 1.--Stand development data sources (except where noted, all data was obtained from the Land Department).

Data	Source
Parent stand condition	Scale reports Phase II inventory Field observations
Stand classification	Phase II inventory Discussions with Land Department foresters
Soil type	Soil Conservation Service type maps

Data was collected from systematically located fixed radius plots. Plots originated from a random location within the stand and were laid out at a density of one plot per three acres with a minimum of two and a maximum of five sample plots per stand. Plot sizes are summarized in Table 2. The following three classes of data were collected from each tree plot: the number of and height of regenerating aspen trees; the species, height, and diameter at breast height of living residual trees; and the average height and density (low, medium, or high) of both woody and herbaceous competition occurring within the tree plot (Competition code source: Minnesota Department of Natural Resources 1981).

Regression Analysis

Regression analyses were performed to indicate which factors were most important to the success (defined by mean stand height and density) of aspen stand development. While all of the aspen stands managed by the Land Department may be classified as being successfully regenerated, this analysis was conducted to determine where the best regeneration was occurring.

When developing the aspen height model, only the tallest 15 percent of the trees surveyed were included. These 15 percent represent the majority of the dominant/codominant trees (for ages two through nine) which are most likely to become crop trees (Perala 1989).

Statistical analyses were performed using the MULTREG statistical package (Weisberg 1986). A stepwise linear regression technique was used to produce lists of "best" models that described stand development success. A final selection of the "best" model was done by calculating and reviewing the PRESS statistic and by applying general forestry knowledge. A case analysis which tested the model for significant outliers, normality, heteroscedasticity and linearity was then conducted for each final model. Final models were approved upon satisfactory completion of these tests. The final models were then further evaluated to determine their appropriateness for the survey data.

For each final model, a spreadsheet was developed using the PC-CALC spreadsheet computer package (Button 1985) to compute values of tree height and number of trees per acre at ages 2 and 9. Inputs to the spreadsheet were coefficients and parameters of each regression model. Output values from the spreadsheet were used to create graphs for visual interpretation of model results.

Table 2.--Field data collection plot sizes.

Cover Type	Plot Size (acres)	Plot Radius (feet)
Aspen (2 to 5 yrs.)	1/1000	3.7
Aspen (6 to 9 yrs.)	1/500	5.3
Competition	1/1000 or 1/500	3.7 or 5.3[1]

[1]Two plot sizes of 1/1000 and 1/500 acre correspond to stand ages of 2-5 years and 6-9 years, respectively.

BREAK-EVEN ANALYSIS

A break-even analysis is a specific type of financial analysis which determines future revenues required to earn a specified rate of return on investments. For this study the break-even analysis was used to calculate revenues (representing future cash flows per acre) required to provide a 3.5 percent real rate of return, considering all stand management costs. If all costs remain constant and revenues exceeded the calculated value, the financial return will exceed the 3.5 percent real rate. However, if costs increase and/or revenues did not meet the calculated value, the financial return would be less than 3.5 percent in real dollars.

Data Collection

Data required for break-even analyses included the costs and timing of all stand management activities and expected revenues from those activities. Cost and revenue data were obtained from the Land Department. All cash flows were obtained in 1989 dollars (Table 3).

Analysis

For each species a break-even discounted cash flow analysis was conducted to determine the total revenue needed to cover all stand management costs. The net present value (NPV) criterion was used in this analysis. An annual 3.5 percent real discount rate, as suggested by the Land Department, was assumed. A real discount rate was used (versus a nominal rate) to eliminate the unknown effects of inflation which occur over time.

This analysis considered final rotations of 35, 40, 45, 50, and 55 years, as suggested by the Land Department. All final harvests were assumed to be by the clearcut method. No intermediate harvests were considered.

The computerized financial analysis package CASH (Belli et al. 1985) was used to calculate necessary revenues for the break-even analysis. Inputs into CASH included discount rates, rotation lengths, all stand management costs (dollars per acre), and estimated stumpage revenues (dollars per acre).

The break-even analysis was performed by first entering all inputs and then making a trial estimate of revenues. This trial estimate was then altered using the resulting NPV and sensitivity analysis information. The final calculated revenues represent the future stumpage value (dollars per acre) required to provide a 3.5 percent real rate of return considering all stand management costs. The break-even stumpage revenue estimate was then converted to volume per acre by dividing by the appropriate stumpage values, as supplied by the Land Department.

Table 3.--Forest management costs and revenues assumed in break-even analyses (1989 dollars).

Factor	
Annual fixed costs	\$0.59/acre
Harvest costs (set-up and administration)	\$5.26/acre
Stumpage revenues[1]	\$5.18/cord

[1]Average value for the period of April 1, 1988 - April 1, 1989.

RESULTS AND DISCUSSION

STAND DEVELOPMENT

Regression models were developed to facilitate an assessment of the most important factors affecting aspen stand development success in stands between the ages of 2 and 9. These models can be used to indicate some of the factors that Land Department foresters should consider when prescribing management treatments. Because these models should not be used to predict tree height or the number of trees per acre at any age, specific model coefficients are not presented here. Instead, there is only a discussion of correlation directions relating to each significant variable. Further studies would be required to develop predicting models.

Height Model

A linear regression model was developed to analyze tree height for the tallest 15 percent of all aspen trees. The model developed accounted for 81 percent of the variation about tree height. Significant variables resulting from this model were stand age, harvest season, site index, basal area of aspen in the parent stand, and soil type (Table 4). A plus or minus sign follows each variable in Table 4, indicating the direction of correlation that the variable has on stand height. For example, the variable stand age has a positive correlation, indicating that as age increases height also increases. All significant variables showed a positive correlation with the exception of site index. Study results indicate that as site index increased, average stand height decreased. This negative correlation may be attributed to the fact that higher site index sites also contained more dense competition which acts to shade and/or crowd out regenerating aspen. However, this trend is not expected to continue as the stand matures. Soil type for this analysis was classified as being either a loam or non-loam soil. The importance of this soil variable is supported by Brinkman and Roe (1975) who state that more vigorous aspen growth is found on loam soil sites which are generally more nutrient rich, higher quality sites (higher site index).

Trees Per Acre Model

The number of aspen trees per acre was also best evaluated by a linear model which accounted for 62 percent of the variation about the number of trees per acre. Therefore, factors other than those examined during the study account for over one-third of the variation in the number of trees per acre. Significant variables resulting from this model were stand age, harvest season, and basal area of living residuals left on the harvest site (Table 5).

Table 4.--Significant variables affecting aspen tree height.

Variable	Direction of Correlation
Stand age	+
Dormant harvest season	+
Site index	-
Basal area of aspen in the parent stand	+
Loam soil type	+

Table 5.--Significant variables affecting aspen tree density.

Variable	Direction of Correlation
Stand age	-
Dormant harvest season	+
Basal area of residuals	-

Stand age was once again the most important independent variable in this model. The negative coefficient for stand age indicates that as stand age increases the number of trees per acre decreases, holding all other variables constant. This is a consequence of the self-thinning process that takes place in aspen stands (Perala 1977). Rates of self-thinning from this study are comparable to estimated changes in stand density that were calculated from an aspen reproduction model by Ek and Brodie (1975). Results from this study (Land Department) indicate that stands thin from approximately 21,000 stems per acre at age 2 to about 5,000 stems per acre at age 9. For a comparable site index of 70 feet, calculated values of stand density (from Ek and Brodie 1975) range from 20,000 stems per acre at age 2 to 6,039 stems per acre at age 10 (Bates et al. 1988).

A positive coefficient for harvest season indicates that more dense regeneration can be expected on stands harvested during the dormant season (dormant season harvest was represented in the model as an indicator variable of value one, while growing season harvest had a value of zero). This result agrees with literature published by Steneker (1972) and Stoeckeler and Macon (1956) who both state that season of harvest is one of the most cited reasons for differences in aspen suckering response. This advantage is generally attributed to the belief that suckering after a dormant season harvest begins simultaneous to other competing vegetation, thereby quickly outgrowing any competition. Suckering after a summer harvest may not appear until the second growing season, thereby allowing competition more time to develop. If sprouts do appear immediately following a growing season harvest, they may still be actively growing in the early fall and therefore susceptible to freezing. It should be emphasized that although dormant harvest season resulted in more dense regeneration, all stands surveyed contained enough stems per acre to be considered satisfactorily stocked.

The number of living, residual trees left on the harvest site was also a significant variable. The negative correlation indicates that for stands with a high basal area of residuals the number of regenerating trees was reduced. Inclusion of this variable in the model is supported by Brinkman and Roe (1975) who stated that one of the most important factors affecting aspen sucker production is the proportion of the parent stand left after harvest. Management guidelines for aspen reproduction state that as little as 10 to 15 square feet basal area of residual overstory will cause detrimental effects on sucker reproduction (Perala 1977). The most important effect of complete clearcutting with no residuals left is the immediate warming of the soil which accelerates sucker initiation and development (Maini and Horton 1964).

BREAK-EVEN ANALYSIS

A break-even analysis of the five aspen rotation lengths indicated that as rotation age increased, the additional volume required to break-even from the clearcut harvest increased at an increasing rate (Table 6). This implies that land managers must carefully consider rotation lengths to maximize profitable aspen management.

Table 6.--Break-even analysis of Land Department aspen management.

Rotation Age (years)	Revenue Required[1] ($/acre)	Volume Required (cords/acre)	Additional Volume Required[2] (cords/acre/year)
35	46.57	8.99	
40	57.49	11.10	0.42
45	70.45	13.60	0.50
50	85.84	16.57	0.59
55	104.12	20.10	0.71

[1]1989 dollars.
[2]Additional volume required was calculated by dividing the difference in volume required between the current rotation age and the previous rotation age by the difference in years between rotations (5 years).

Break-even volumes were compared to normal yields for aspen occurring in the North Central states (Perala 1977) (Figure 1). The plot of Land Department required volume (this study) versus North Central states expected yields at various site indices (Perala 1977) and ages shows that the necessary volume required to cover incurred management costs may never be achieved on site index 50 stands, given current assumptions. Management costs would be recovered for site index 70 sites for all stand rotation lengths at least 40 years in length, the minimum age in the published report. For site index 60 sites, management costs would be recovered for rotations greater than age 45.

An evaluation of the Land Department's computerized inventory indicated that the percent of acres with sufficient aspen volume to at least break-even decreases from 73.4 percent (rotation age = 35) to 22.8 percent (rotation age = 55) (Table 7) assuming a minimum harvestable age of 30 years. When no minimum age was assumed, the percentage of stands yielding a break-even volume was smaller, especially at younger rotations. These apparently low percentages are, in part, due to a large number of young aspen stands that are less than 15 years old.

SUMMARY AND CONCLUSIONS

Observational stand development and break-even analyses for aspen were performed in stands aged 2 to 9 years old on lands managed by the Beltrami County Land Department. Aspen dominant and codominant tree height was most affected by stand age, harvest season, site index, basal area of aspen in the parent stand, and soil type. Aspen stands regenerating from parent stands with a higher stocking of aspen usually produced taller trees when harvested during the dormant season and growing on loam soils. Although all aspen stands appeared to contain sufficient stocking to develop to fully stocked conditions at rotation, stands harvested during the dormant season with few residuals left on site contained the highest stocking levels at age nine.

The break-even analysis of aspen management indicated that as rotation age increases, the additional volume required to cover costs from the clearcut harvest increased at an increasing rate. Percentages of aspen stands managed by the Land Department that currently have sufficient volume such that harvesting today would at least provide a break-even range from 73 percent (rotation at 35 years) to 23 percent (rotation at 55 years) when stands at least 30 years old are included in the analysis. Where site index is less than 60, management costs may never be recovered, versus where site index is greater than 60 management costs should be recovered with rotation lengths greater than 45 years.

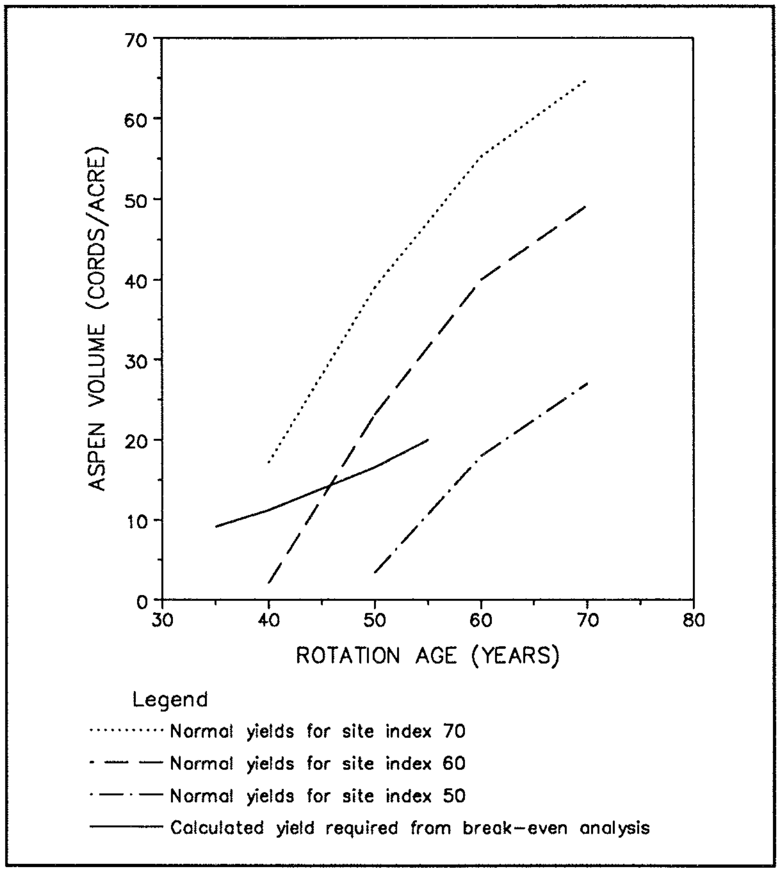

Figure 1.--Normal yields of aspen occurring in the Lake States (Perala 1977) versus calculated break-even volumes.

Table 7.--Land Department stands with necessary aspen volume to at least break-even with incurred management costs.

		30 Years <= Age <= rotation		Age <= rotation	
Rotation Total (years)	Volume Required (cords/acre)	Acres with Volume Required	Percent of Total Acres[1]	Acres with Volume Required	Percent of Acres
35	8.99	2,387	73.4	3,488	23.9
40	11.10	4,635	59.4	5,147	26.8
45	13.60	7,977	43.8	8,254	27.9
50	16.57	9,861	32.9	9,918	24.6
55	20.10	7,991	22.8	8,012	17.3

[1]Percent of all aspen acres was calculated by dividing the number of acres meeting volume requirement by the total number of aspen acres less than or equal to the respective rotation age. Acreages were determined through a computer search of the Land Department's Phase II inventory. Only stands where aspen is the primary cover type were included in these calculations.

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ECOSYSTEM CARBON FOLLOWING ASPEN HARVESTING IN THE UPPER GREAT LAKES

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ABSTRACT.--Whole-tree and merchantable bole harvesting of three mature aspen stands in Minnesota and Michigan removed 24 to 48 percent of total ecosystem carbon, but neither harvesting system affected the weight of forest floor carbon or organic soil carbon (to a depth of 50 cm) for up to 8 years. Litterfall returned nearly to pre-harvest levels within 5 years. Vegetative biomass recovered equally as fast in both harvesting treatments at all study sites. Timber harvesting on similar sites is unlikely to affect the amount of soil organic matter.

INTRODUCTION

Soil organic matter is one of the major factors determining forest site productivity (Carmean 1975). Losses of organic matter from a site often reduce productivity in both agriculture (Tate 1987) and forestry (Powers et al. 1990). The amount of organic matter in a soil is the net result of additions (primarily litterfall in forests) and oxidation by microorganisms. When sites are disturbed, as by plowing and conversion to agriculture, soil organic matter often changes, and within a half century or so a new equilibrium of soil organic matter becomes established. Mann (1986) showed that organic matter losses following cultivation are proportional to the initial soil organic matter content and seldom exceed 20 percent of the initial values.

In forestry, the results are mixed; some studies show loss of soil organic matter after harvesting (Burger and Pritchett 1984, Covington 1981, Mroz et al. 1985), but others show little or no change (Edwards and Ross-Todd 1983, Gholz 1982, Wallace and Freedman 1986). In general, when soil organic matter is lost following harvesting, it is primarily from the forest floor; however, separating the forest floor from the underlying mineral soil is notoriously difficult (Federer 1982), and it is seldom clear whether reported losses are losses or simply redistribution within the soil profile.

Aspen (Populus tremuloides Michx. and P. grandidentata Michx.) are rapidly growing trees of extreme commercial importance in the upper Great Lakes. Aspen lends itself to intensive harvesting systems, and much of the aspen harvest now incorporates removal of the entire aboveground part of the stand from the site. Whole-tree removal raises a concern about site productivity declines through loss of nutrients and organic matter from the site. This concern has been addressed at a number of recent conferences (Agren 1986, Ballard and Gessel 1983, Williams and Gresham 1988), and in the soon-to-be-published Proceedings of the 7th North American Forest Soils Conference. Extensive removal of organic matter, such as in litter raking, can significantly impact site productivity (Assmann 1970, McLeod et al. 1979). In addition, on at least some sites, the removal of logging slash has reduced subsequent tree growth in comparison with operations in which only the tree boles are removed

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(Balneaves 1989, Lundkvist 1987, Mann et al. 1988, Sterba 1988). We are not aware of any studies showing loss of productivity attributed to whole-tree harvesting of aspen, but we do know that whole-tree harvesting of aspen removes more organic matter and nutrients from the site than does bole-only harvesting. Eventual impairment of productivity on some sites seems, therefore, possible (Pastor and Bockheim 1984, Perala and Alban 1982).

We conducted a study to experimentally harvest mature aspen stands on a range of sites by whole-tree and bole-only methods and to determine the effects on ecosystem organic matter and subsequent vegetative recovery.

METHODS

We harvested aspen stands on three sites that contrasted strongly in productivity and soils (Table 1). The study sites were from 12 to 20 ha in size. Each site was divided into 1-ha treatment blocks. The harvesting treatments (replicated four times) were: clearcut whole-tree (CWT)--remove all trees greater than 2.5 cm DBH from the site; clearcut merchantable bole (CMB)--remove only merchantable boles to a 10 cm top; and uncut-controls (U). The Ottawa and Pike Bay sites were logged in the winters of 1980 and 1984, respectively, when the ground was snow-covered and frozen. The Cloquet site was logged during the summer of 1979 with care to prevent skidding over the measurement plots. Thus, mechanical disturbance was kept to a minimum on all sites, and any changes in soil organic matter changes reflect tree removal and not physical disruption of the site. After harvesting, four of the blocks at Ottawa and Cloquet and eight blocks at Pike Bay were allowed to naturally regenerate to aspen, whereas four blocks at each site were converted to white spruce (Picea glauca (Moench)Voss) following site preparation (Perala 1987). Results from these conversion treatments are not reported here.

Before harvesting, tree biomass was determined by felling trees of a range of diameters, oven-drying the component subsamples (bolewood, bolebark, branches, and foliage), and developing regression equations to relate component biomass to DBH and height. Stand values were then developed allometrically from these diameters and heights on .05-ha permanent measurement plots (four per ha).

Shrub layers (<25 mm DBH) were sampled before harvesting and 1, 2, 3, 5, and 8 years after harvesting. Stand shrub biomass was estimated allometrically from calipered diameters on 0.5- to 4-m^2 plots.

Table 1.--Characteristics of the study sites.

Site	Location	Soils	Annual Ppt (cm)	Pre-harvest Vegetation: Stand Age (yr)	Basal Area (m^2/ha)	Aspen Site Index (m @50 yr)
Ottawa	Ottawa N.F. Michigan U.P.	Ontonagon clay	77	47	24.7	18.1
Cloquet	Cloquet Exp. For. NE Minnesota	Cloquet fine sandy loam	76	60	19.1	17.0
Pike Bay	Pike Bay Exp. For. NC Minnesota	Warba very fine sandy loam	64	66	38.3	24.2

Herbs were clipped in late July before harvest and 1, 2, 3, 5, and 8 years after harvest from 0.5 m^2 plots and oven-dried for direct biomass determination.

Littertraps (0.4 m^2) were installed on each site and emptied six times per year. Woody debris, including large downed materials and the logging slash after harvesting, was sampled from fixed area plots on all sites immediately after harvesting and 5 years after harvesting at the Ottawa and Cloquet sites. All vegetation samples (trees, shrubs, herbs, litterfall, and woody debris) were dried at 75°C. Carbon concentration for all of these materials was assumed to be 50 percent of the ovendry weight (Linder and Axelsson 1982). Root samples (>5 mm) were collected from only the pre-harvest shrub layer. The allometric relations derived from the root samples were applied to post-harvest shrub vegetation as well. Roots of mature trees were estimated as 20 percent of aboveground biomass (Perala and Alban 1982, Ruark and Bockheim 1987).

Soil samples were collected with a 10-cm diameter sampling device (Jurgensen et al. 1977) before harvesting, annually for 4 years after harvesting, and every other year thereafter. Soil cores were partitioned into the forest floor, surface soil, and soil remaining to a depth of 25 cm. A further sample from the 25- to 50-cm depth was collected with a bucket auger. Forest floor samples were dried at 75°C and then ground to pass a 20-mesh screen. The ash content of the forest floor was determined by ashing in a muffle furnace at 525°C for 2 hours. The mineral soil samples were air-dried (a subsample oven-dried at 105°C) and passed through a 2-mm screen. Total carbon in both forest floor and mineral soil samples was determined with an induction furnace.

RESULTS AND DISCUSSION

Whole-tree harvesting reduced ecosystem carbon dramatically on all three sites (Fig. 1). For Ottawa, Cloquet, and Pike Bay, the aboveground biomass contained 38, 44, and 62 percent, respectively, of total ecosystem carbon. Harvesting the major part of this biomass clearly reduced carbon in the system. Recovery of carbon by photosynthesis of the regrowing vegetation replaced 19 and 15 percent of the loss at Ottawa and Cloquet, respectively, in 8 years; and 9 percent of the loss at Pike Bay in 5 years (Fig. 1).

Woody debris, most of which was logging slash after harvesting, was a small part of total ecosystem carbon (Fig. 1). Logging slash for the CMB treatment was about two to three times that of the CWT treatment (Table 2); but even for the CMB treatment, logging slash was only about 20 percent of the aboveground biomass before harvest. This 20 percent roughly corresponds to the proportion of aspen biomass contained in the branches and top (Pastor and Bockheim 1984, Perala and Alban 1982). The logging slash was reduced by about one-half after 5 years at Ottawa and Cloquet (Table 2).

Ecosystem carbon is clearly reduced directly by removals in harvesting, but the more important question from the site productivity standpoint is whether soil carbon is reduced.

We find no evidence that harvesting affected carbon weight in the forest floor for harvesting treatments (Table 3). The only case where forest floor carbon declined was in the uncut blocks at Cloquet. This special case, involving incorporation of the forest floor into the mineral soil by earthworms, will be discussed later.

Because defining the forest floor mineral soil boundary is difficult, we are more comfortable sampling both the forest floor and the mineral soil to a depth that includes most of the soil organic carbon (50 cm here). Such sampling produces far less variable soil carbon data than sampling the forest floor alone. Harvesting has not altered total soil carbon (Table 4). At Cloquet and Pike Bay, soil carbon, both before harvest and for the last year measured, is nearly identical among the uncut and harvested treatments. At Ottawa, carbon in the uncut plots is less than in the harvested plots, but by the same amount pre- and post-harvest, again indicating no effect of harvesting on soil carbon.

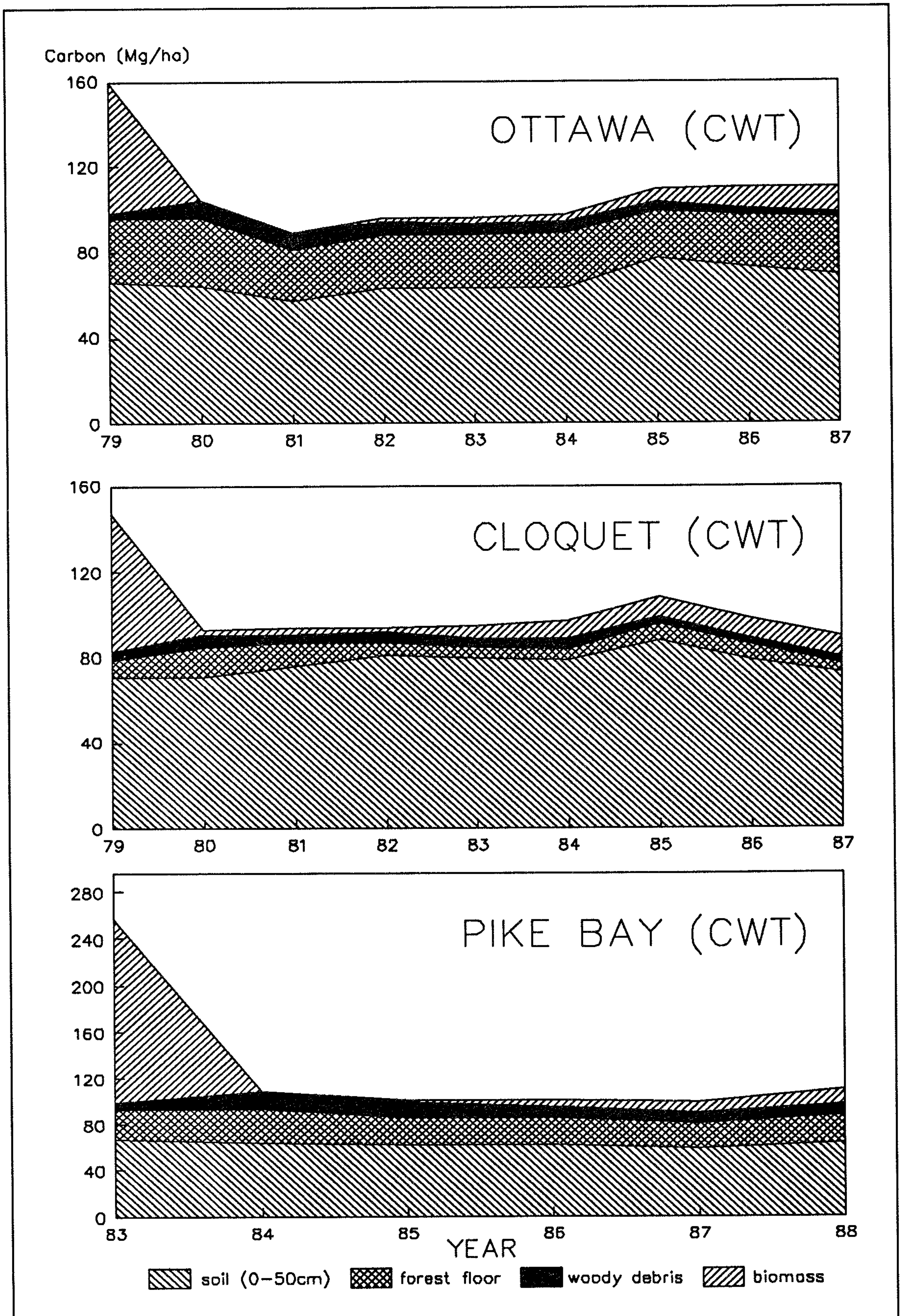

Figure 1.--Ecosystem carbon for the whole-tree harvested (CWT) areas.

Table 2.--Logging slash carbon.

Site and Treatment	Initial (Mg/ha)	After 5 Years (Mg/ha)
Ottawa		
CWT	5.7	2.7
CMB	9.0	3.9
Cloquet		
CWT	2.3	1.9
CMB	7.3	2.7
Pike Bay		
CWT	9.6	---
CMB	32.2	---

Table 3.--Forest floor carbon.

Site	Treatment		
	Uncut (Mg/ha)	CWT (Mg/ha)	CMB (Mg/ha)
Ottawa			
Pre-harvest	29.0	29.3	26.5
Post harvest[1]	23.1	25.5	23.0
Cloquet			
Pre-harvest	15.4	8.0	5.1
Post harvest[1]	10.7	7.5	5.2
Pike Bay			
Pre-harvest	23.0	25.4	19.7
Post harvest[1]	25.9	25.2	24.9

[1]The mean of all years after harvesting.

Soil carbon is a balance between inputs and losses through decomposition. Harvesting adds slash to the soil surface (Table 2), but the slash incorporates slowly into the soil. This is somewhat balanced by the lower amount of litterfall added to the soil for the first few years after harvesting. It is surprising that soil organic matter following harvesting is nearly identical among the CWT and CMB treatments. Perhaps root detritus is responsible. Root detritus appears to be about equal to the aboveground slash for the CMB treatment. Thus, total detritus for the two logging treatments would differ far less than indicated for the aboveground slash alone (Table 2).

Table 4.--Carbon in the forest floor and mineral soil to a depth of 50 cm.

Years Since Harvest[1]	Ottawa Uncut	Ottawa CWT	Ottawa CMB	Cloquet Uncut	Cloquet CWT	Cloquet CMB	Pike Bay Uncut	Pike Bay CWT	Pike Bay CMB
	(Mg/ha)								
0	80	95	90	74	76	71	63	66	59
1	75	96	84	72	82	66	66	63	64
2	79	81	76	71	83	72	66	62	61
3	74	86	82	78	82	73	59	61	55
4	--	--	--	--	--	--	64	58	62
5	76	87	88	69	80	70	65	62	64
6	81	97	98	73	90	77	--	--	--
7	--	--	--	--	--	--	--	--	--
8	76	92	92	73	71	74	--	--	--

[1]"0" is pre-harvest.

Harvesting on our sites did not affect total soil carbon, but physical disruption on our sites was minimal. It is conventional wisdom that mixing the forest floor with the mineral soil may accelerate decomposition (Armson 1977). We have two lines of evidence from Cloquet that indicate accelerated decomposition may not always occur following mixing:

1. Earthworm mixing - At Cloquet, earthworms were common and mixing was so thorough in most plots that little forest floor remained and most soil organic matter was contained in an A horizon. On some of the control plots, however, earthworms were initially present in low numbers and a well-developed forest floor was present along with only a thin A horizon. We noted with each succeeding year less and less forest floor in the controls, more A horizon, and more earthworms. By the eighth year the forest floor in the controls was nearly the same as in the harvested plots. Over the course of the study, carbon in the forest floor of the controls declined from 21 percent of total soil carbon to 6 percent. Similar rapid soil changes also were noted in New Brunswick after earthworm invasion (Langmaid 1964). Despite strong soil mixing and the dramatic change in the character of the soils over 8 years, the total amount of carbon in the soil did not change (Table 5).

2. Soil disking - At Cloquet, four additional 1-ha blocks were partially harvested, leaving a shelterwood paper birch (Betula papyrifera Marsh.) (Perala and Alm 1989). These blocks were disked in October 1980 to prepare them for natural regeneration. The logging slash and forest floor were thoroughly mixed into the mineral soil; nevertheless, total soil carbon did not change over 7 years (Table 5).

If thorough soil mixing by earthworms and disking did not change soil carbon, perhaps treatments far more site disruptive than our careful logging may not alter total soil organic matter, either.

Table 5.--Carbon in the forest floor and mineral soil (0-50 cm) at Cloquet following earthworm increases and disking.

Treatment	0	1	2	3	5	6	7	8
	Years Since Harvest (Mg/ha)							
Uncut (earthworms)	74	72	71	78	69	73	--	73
Disked	70	--	--	--	72	68	68	--

We find little difference in the effects on the site between CWT and CMB harvesting. Vegetative productivity provides further evidence. For the last year of measurement (8 years since harvesting for Ottawa and Cloquet, and 5 years for Pike Bay), there is no difference in the total biomass between the two harvesting regimes:

	Biomass (Mg/ha) CWT	CMB
Ottawa	23.6	25.1
Cloquet	18.7	18.6
Pike Bay	28.5	28.1

Soil organic matter weight was not altered by harvesting, and we see little reason for it to change in the future. The sites have revegetated with complete crown cover so that the microclimate is similar to that before harvest. More than half of the logging slash has disappeared, and it will be added only slowly in the future. Organic matter addition through litterfall is nearly back to pre-harvest levels at the Ottawa and Cloquet sites, and approaching that level at the Pike Bay site (Table 6). We conclude that on sites such as these, timber harvesting is unlikely to have any impact on the soil organic matter mass.

Table 6.--Annual litterfall (including herbs).

Years Since Harvesting	Ottawa		Cloquet		Pike Bay	
	Uncut	Cut[1]	Uncut	Cut[1]	Uncut	Cut[1]
	(Mg/ha)					
0	3.7	3.2	3.2	2.7	3.5	3.8
1	3.8	.7	3.0	1.0	3.9	.8
2	4.0	2.2	4.2	3.0	4.0	1.5
3	3.8	1.9	4.4	2.0	4.3	2.5
4	---	---	4.2	2.6	---	---
5	4.1	3.7	---	---	4.3	2.6
6	---	---	4.6	4.0	---	---
7	---	---	---	---	---	---
8	3.3	2.7	3.3	2.9	---	---

[1]Average of CWT and CMB treatments.

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MANAGEMENT OF ASPEN FOR RUFFED GROUSE AND OTHER WILDLIFE - AN UPDATE

Gordon W. Gullion[1]

ABSTRACT.-- The aspens (Populus tremuloides; P. grandidentata) are the basic habitat resource for ruffed grouse (Bonasa umbellus) across the major portion of this bird's North American range. The occurrence and welfare of these birds is closely associated with the presence and condition of aspen stands. The aspens provide critical food and cover for these grouse, and this has permitted the development of specific guidelines for forest managers to use to maintain or improve habitats for these birds. But continuing research and the recent identification of a feeding deterrent, coniferyl benzoate, in the male flower-bud has necessitated some changes in recommendations relative to the maintenance of winter food resources. The cover requirements of ruffed grouse have become well defined and predicted responses have resulted from prescribed aspen clearcutting. The best quality of cover is provided by aspen saplings 5- to 25-years old with densities in the range of 3,000 to 8,000 stems/acre. The most productive size of treatment has been 1-acre blocks, but 10-acre blocks of aspen regeneration support breeding grouse densities in excess of 10 pairs/100 acres, a density more than 10-fold greater than in nearby >50-year-old northern hardwood forests. Precommercial thinning may or may not have a detrimental impact on subsequent grouse abundance. This effect will probably depend upon the understory shrub response to the thinning. The forest manager has the opportunity to rather precisely determine how many breeding grouse will live in areas under his or her control by the management prescriptions involving the maintenance of aspen.

At the 1972 Aspen Symposium here in Duluth I identified the aspens as being the basic habitat resource for ruffed grouse across the major portion of their range (Gullion and Svoboda 1972). At that time it was a novel idea and not widely accepted (some authors still don't accept it - see Bergerud and Gratson 1988:691). But other studies underway at that time (Rusch and Keith 1971, Doerr et al. 1974), or initiated subsequently (Huemphner 1981) have reinforced the validity of my original position.

I don't believe it is coincidence that by far the greatest abundance of ruffed grouse is in North American forests where aspen is a part of the forest composition. While these grouse also live in some areas where aspen is not present, these are almost entirely areas where winter snow cover is not persistent. Also, densities of breeding grouse in regions extralimital to the range of aspen tend to be only a fraction of the densities in areas where aspen is present, especially in interspersed age-classes (Table 1).

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Table 1.--Representative ruffed grouse densities as related to the occurrence of aspen in the forest composition.

Area	Density/ 100 Acres[1]	Forest Composition	Reference
		Aspen Regeneration	
Michigan - Gladwin Refuge	10 - 13	5-15 year-old aspen	Prawdzik (unpublished)
Minnesota - Cloquet Forest	9.3	10-25 year-old regen.	Gullion & Alm (1983)
Mille Lacs WMA	8.0 - 15.3	5-15 year-old aspen	Gullion (1989)[2]
Wisconsin - Sandhill WMA	6.8	Aspen regen. w/alder	Kubisiak et al. (1980)
		Mature Aspen Present	
Alberta, Canada	1.8 - 4.1	Spruce-aspen	Boag (1976)
Alberta, Canada	5 - 9	Mature aspen	Rusch & Keith (1971)
B.C., Canada	3.2 - 4.2	Mixed aspen-Douglas-fir	Davies & Bergerud (1988)
Idaho	2.8	>80 year-old aspen	Stauffer & Peterson (1985)
Michigan - Midland	0.9 - 2.1	Mature aspen-hardwood	Haufler (1989)[2]
Minnesota- Mille Lacs WMA	0.7	Northern hardwood	Gullion (1989)[2]
Ohio	0.8 - 1.8	Mixed conifer-hardwood	Stoll et al. (1979)
Ontario, Canada	4.5	Mixed conifer-hardwood	Theberge &Gauthier (1982)
Pennsylvania	1.3 - 2.8	Northern hardwood	Drake (1989)[2]
Vermont	1.07	Mixed hardwood/conifer	Sousa (1978)
Wisconsin - Stone Lake	3.0	Mature aspen & balsam fir	Kubisiak et al. (1980)
		No Aspen	
Georgia	0.72 - 1.05	Oak-hickory hardwood	Hale et al. (1982)
Missouri	0.57	Mixed oak hardwood	Thompson & Fritzell (1989)
Ontario	2.9	Mixed conifer-hardwood	Theberge & Gauthier (1982)
Pennsylvania	0.8 - 1.4	Oak-hickory hardwood	Drake (1989)[2]
Tennessee- Catoosa WMA	0.15 - 0.23	Oak-hickory hardwood	Dimmick (1989)[2]
Cherokee NF	0.25 - 0.33	Oak-hickory hardwood	Dimmick (1989)[2]
Washington	2.3 - 2.6	Mixed deciduous-conifer	Brewer (1980)

[1]Based on drumming males and approximately equals breeding pairs in spring.

[2]Data extracted from unpublished progress reports submitted to The Ruffed Grouse Society.

I believe ruffed grouse have evolved in North American forested environments to take advantage of the unique characteristics of the aspens. These characteristics include fleshy, highly-palatable leaves for a summer-long food resource; a winter-long abundance of large, nutritionally-rich, staminate flower-buds set on stout twigs, which later develop into large, nutritious catkins just prior to the grouse breeding season; and a method of root-sucker regeneration that for a number of years provides secure, uncluttered, evenly-spaced vertical cover, to a degree unmatched by any other form of northern forest vegetation.

Since aspen has the widest distribution of any tree in North America, and occurs in at least 27 percent of the forested acreage on the continent (Gullion 1977, 1985), it is not surprising that ruffed grouse, by taking advantage of the aspen resource, have the widest distribution of any resident game bird on the continent. These grouse occur in Alaska, all of the Canadian provinces, and in 39 of the 48 contiguous United States.

Johnsgard (1973:257) suggests a relationship between the range of ruffed grouse and the occurrence of balsam-poplar (Populus balsamifera). These birds seldom utilize any part of this tree, and there is no biological basis for this association.

Even in localized areas there is a marked association between the distribution of aspen and the persistent occurrence of ruffed grouse. On the Cloquet Forest, 20 miles west of the site of this symposium, where aspen occurs in only about 11 percent of the forest, 87.6 percent of 210 persistently used drumming logs (by 4 or more birds or for longer than 5 years since 1956) were under or within sight of mature male aspens. Another 13 (6%) were in sapling aspen stands out-of-sight of mature aspen. On the Mille Lacs study area, 90 miles farther to the southwest, aspen comprises only about 14 percent of the hardwood forest composition, and 88 percent of the occupied drumming logs there have been under or within sight of mature aspens. Aspens were within sight of 96 percent of 138 drumming logs surveyed in Maine (Schemnitz 1976). In southeastern Ohio hardwood forests, where aspen comprises less than 1 percent of the forest stand, 53 percent of the ruffed grouse drumming logs were within 100 m (328 feet) of aspen (Stoll et al. 1979).

Huff (1973) examined in more detail the nutritive qualities of aspen flower-buds in Minnesota, as did Doerr et al. (1974) in Alberta, Canada. Huemphner (1981) provided additional, more detailed information concerning ruffed grouse foraging behavior in another Minnesota site. In a round-about way the classic New York ruffed grouse study inferred a more than casual relationship between these birds and aspen by the comment:

> The large buds, long catkins, and tough leaves set on stout twigs of the aspens (Populus) are particular favorites even when other food is abundant (Bump et al. 1947:201).

THE ROLE OF ASPEN AS FOOD

The importance of aspen as a food resource has long been recognized (Svoboda and Gullion 1972) and has been included in aspen management prescriptions since 1972 (Gullion 1972). The 1986 forest management plans for the Superior National Forest (U.S.F.S. 1986) acknowledged the importance of this resource in the specification:

> When the [aspen] harvest area is greater than 20 acres and mature aspen is not within 10 chains (660 feet) of the periphery of the stand, one clone of mature male aspen should be left standing.

In Minnesota, both at Cloquet (Svoboda and Gullion 1972) and Cedar Creek (Huemphner 1981) where both quaking and big-toothed aspen occur together ruffed grouse have shown a preference of about 2:1 for quaking over big-toothed when compared to the relative abundance of the two tree species. The male flower-bud is most often fed upon but enlarged female buds are taken occasionally.

Most of the emphasis has concerned the role of aspen flower-buds as a winter food resource. Less attention has been given to the use of the staminate catkins that elongate in early spring. As more is learned about these birds and their needs it appears that these catkins may be more important than the flower-buds as a food resource, albeit for a short period of time.

On the Minnesota study areas (Cloquet and Mille Lacs), without fail, the extended catkins have been the nearly exclusive diet of drumming male ruffed grouse (and we suspect, of females as well) for the two or three weeks in April that they are available. This statement is based on the classification of tens of thousands of droppings at more than 2,000 drumming sites over the past quarter century. Regardless of what ruffed grouse have been using all winter, and the availability of other food resources as the snow melts (especially the green leaves of frost-resistant herbs such as strawberry (Fragaria sp.), bunchberry (Cornus canadensis), gold-thread (Coptis groenlandica, etc), aspen catkins are nearly the exclusive diet for a short time. Once the pollen has been shed and the catkins dry up and begin to fall grouse turn their attention to willow catkins or the leaves of the frost-resistant forbs. As soon as aspen leaves begin to emerge many grouse begin feeding on these, with the leaves of male aspens being preferred.

Few other ruffed grouse studies have focussed on the feeding behavior of grouse at this critical season, but Stoll et al. (1980) found heavy use of aspen catkins by male ruffed grouse in southeastern Ohio where aspen is scarce.

Our continuing studies have shown that the flower-buds are not a dependable winter food resource even when physically available. As early as 1973 we realized that ruffed grouse were inconsistent in the use of aspen flower-buds, and that extent of use was not related to the annually varying abundance of buds. In some seasons ruffed grouse make almost no use of the flower-buds even when abundant on the trees. There is always a high level of selectivity in the choice of aspens to be fed in. Normally a very small percentage (<10%) of the male aspens provide an acceptable, winter-long food resource for ruffed grouse.

Bump et al. (1947) noted that variations in grouse use of aspen buds and catkins (and some other food items) was not necessarily related to their abundance and availability. They commented:

> it seems clear that changes in utilization are many times dictated not by availability, but rather by some other factor not yet apparent (p.219).

Doerr et al. (1974:609) noted that grouse use of aspen flower-buds declined sharply from the winter of 1969-70 (47 percent of crop volume) to the winter of 1970-71 (3 percent of volume), even though bud availability appeared to remain relatively constant.

But there has been unvarying, consistent use of the extended catkins in the spring, and it seemed probable to us that some substance in or on the flower bud-scales was acting as a feeding deterrent.

Recently completed research here has identified a phenol, coniferyl benzoate concentrated in the bud scales, as the apparent feeding deterrent (Jakubas 1989, Jakubas et al. 1989, Jakubas and Gullion 1989). It is suspected that periodic variations in ruffed grouse abundance (the grouse "cycles") are at least partly a consequence of periodic changes in the amount of this phenol in aspen flower-buds (Gullion 1984a). Annual variations in the amount of protein in these buds may also play a role (Jakubas 1989). Longer-term studies are needed to validate this relationship.

MODIFICATION OF EARLIER RECOMMENDATIONS

These findings indicate a need to modify some earlier recommendations concerning provision of winter-long food resources (Gullion 1984b:28). The practice of leaving small groups or clones of male aspens scattered at the rate of one every 10 to 20 acres in extensive aspen clearcuts probably will not be effective unless several clones of male aspens are involved. This, then, means leaving patches that are probably at least one or two acres in extent, rather than a few dozen trees.

Since the amount of coniferyl benzoate in the flower-buds of individual trees fluctuates between years (Jakubas 1989), preservation of identified feeding trees is not assurance that those trees will be chemically suitable for utilization in the future. The most satisfactory provision of adequate winter-food resources, and the maintenance of ruffed grouse abundance is probably dependent upon even-area, 3- or 4-stage rotational, clearcut harvesting in dispersed blocks, not over 20 acres in size (see Gullion 1984b).

But even more important, these findings, together with the very little winter use of aspen flower-buds during most of the past decade, indicate the need to maintain ample, alternative winter food resources for ruffed grouse. In northern Minnesota hazel (Corylus sp.) is the most important of these alternative resources, with birch (Betula sp.) of secondary importance. Elsewhere, in the range of aspen, ironwood or hophornbeam (Ostrya virginiana) may replace hazel in importance. The 3- or 4-stage rotational harvesting described earlier will usually meet this need for adequate alternative food resources.

We now regard alder (Alnus sp.) to be virtually useless as a grouse food. Most other widely used food materials are either too uncommon or only seasonally available in aspen forests, and not dependable over a wide area on a winter-long basis. This includes the roses (Rosa sp.), cherries (Prunus sp.), juneberry (Amelanchier sp.), mountain ash (Sorbus sp.), blueberries (Vaccinium sp.), and a few others.

ASPENS AS GROUSE COVER

At the time of the 1972 Aspen Symposium we had only begun to appreciate the role aspen plays as year-around cover for ruffed grouse. Subsequently this role has become very apparent and the parameters of premium grouse cover have become well defined (Cade and Sousa 1986). Research spanning more than 30 years has documented these relationships. This has involved observing the use, abandonment, reuse and abandonment again of forest tracts that have been clearcut. These are stands that were allowed to regenerate to aspen, and watched as the aspen stand developed through a period when it supported high density ruffed grouse populations (as high as reported anywhere on the continent), which eventually declined as the aspen stand became too old and open.

Aspen regeneration is most useful as grouse cover from the time it thins to about 8,000 stems/acre, until natural thinning brings the density below about 3,000 stems/acre (Gullion 1984b, Cade & Sousa 1986).

The timing of this usefulness depends upon at least two factors, one environmental and one a management decision. On the poorer soils on the Cloquet Forest satisfactory densities develop about 10 years following harvesting. Then about 15 years later the lower density threshold is reached at which grouse abandon aspen stands.

On heavier soils and a warmer climate at Mille Lacs, but under the same management regimen, aspen stands are commonly in use by 5 or 6 years after harvesting. But in another 10 years they have thinned too much and "gone-by" when they are about 15 years old. This same timing occurred in aspen regeneration areas on the Gladwin Refuge on Michigan's Lower Peninsula (Prawdzik, unpubl. data).

The management decisions that can affect this sequence are mostly related to age of the stand when harvested and season of harvesting, and relationships between these two factors.

Ideal aspen sucker regeneration should initially exceed 12,000 stems/acre. This assures highly competitive growth, resulting in the saplings concentrating growth in the terminal tips. These saplings grow straight with minimal lateral branching. Sufficient height, usually at least 18 feet, is also an important factor governing grouse use of aspen regeneration.

Aspen stem densities do not have to be uniform over an entire area, so long as there is at least an acre of adequate stem density for each 8 to 10 acres of regeneration. One such block of cover should be present wherever a pair of breeding grouse is desired.

EFFECT OF TREATMENT SIZE

The best overall habitats for ruffed grouse are those in which the year-long needs for food and cover are obtained with the least amount of movement. Movement is expensive, both in the use of energy and the increased exposure to predation. On the other hand, social interactions limit the numbers of grouse that can be supported in one area. Each adult male requires 6 to 8 acres for his exclusive territory, with hens content to use the territories of 2 or 3 males for their winter ranges.

On the Mille Lacs area a major effort has been directed towards determining the most productive harvesting configurations from the standpoint of grouse response. Based on 20 years of experience, 1-acre clearcuts with good aspen regeneration have provided the highest response/acre cut. A series of 1-acre cuts made in 1968 to 1973 were being used at the rate of 1 breeding male/2.3 acres cut by 1977 (Gullion 1983).

By contrast, of 32 clearcuts less than 1-acre in size made at the same time, only 5 have been used by breeding grouse. There seems to be a 1-acre size threshold that must be reached or exceeded before a clearcut will become an acceptable covert for ruffed grouse winter and breeding season use.

Since 1974 we have cut about 716 acres on 67 parcels varying from 5 to 40 acres in size. Some of these were cut as strips 5 chains wide and 20 chains long (330 x 1320 feet), the others in as nearly square blocks as topography would allow. Table 2 shows the current grouse response to these differing treatments. Within the last 5 years we have also made 52 2-1/2 acre clearcuts on one 305-acre tract. But it is too early to expect response to this treatment.

Table 2.--Densities of breeding male ruffed grouse - Mille Lacs.

Treatment	Acreage[1]	No. Birds		Density/100 Acres	
		1988	1989	1988	1989
10-Acre Blocks	129	14	17	10.9	13.2
10-Acre Strips	259	13	11	5.0	4.2
Blocks exceeding 20 Acres	103	9	13	8.7	12.6
Uncut Forest[2]	412	3	3	0.7	0.7

[1]Based on regenerated aspen coverts logged between 1974 and 1978, and currently at the optimum stage of development. More recent cuttings where the vegetation has not reached proper density are not included.

[2]A reserved area of >50 year-old forest that supported 14 male grouse (= pairs) in 1971.

Ruffed grouse response to this management has not been as expected, with the blocks receiving considerably heavier use than the 10-acre strips (see Gullion 1984b:24). The Mille Lacs WMA is subjected to exceptionally heavy fall hunting pressure and the area cut in strips is more heavily hunted than that cut in blocks (Gullion 1988). So the effect of hunting may be obscuring the level of response that would occur in areas with lighter hunting pressure.

INTEGRATION OF GROUSE BENEFITS INTO CONIFER PLANTATIONS

Generally coniferous cover is detrimental to ruffed grouse in northern forested environments. Tables 1 and 2 show that breeding grouse densities are generally lower where coniferous cover is present than where aspen is present but conifers absent.

Recent observations at Cloquet have shown that 1- to 2-acre pockets of aspen scattered in a conifer plantation can provide highly acceptable habitat for ruffed grouse. This has been associated with the establishment of a red and jack pine (Pinus resinosa; P. Banksiana) plantation on a 48-acre site clearcut in 1969. Small pockets of aspen regeneration developed on the periphery of this plantation, and in 1984 ruffed grouse began using these aspen sites. By 1989, 9 males were using this area and an adjacent 7.4-acre 32-year-old pine plantation (having much aspen mixed through it). This density of 14.4 males/100 acres is about as many breeding grouse as reported anywhere (see Table 1), and is probably about 4 to 6 times the density of breeding ruffed grouse in most northern Minnesota forested areas.

These discrete pockets of relatively pure aspen appear to be more useful than having aspen scattered throughout a pine plantation. At Cloquet where the latter condition prevails maximum concurrent grouse densities have remained at about one-third the densities attained where these aspen pockets provide cover.

The delayed occupation of these aspen sites (at 14 years after treatment rather than the usually expected 10 years) evidently resulted from the absence of readily available, catkin-producing male aspens within a close proximity. Grouse use was delayed until the young aspens growing on the site commenced producing catkins.

The forest manager intending to integrate grouse coverts into conifer plantation sites can establish the density of birds to be supported by deciding how many 1-acre blocks of aspen regeneration are to be left in the affected area. One block per 10-acres is probably about the maximum desirable, due to the social intolerance of these birds. But in 1989 we had 4 males (all trapped and banded) sharing one area of less than 10 acres.

This high density breeding grouse population has been maintained within 1/2-mile of an active goshawk (Accipiter gentilis) nest throughout this period. In 1988 one 5-year-old and two 2-year-old grouse were in this group, and two 2-year-olds were present in 1989.

NON-GAME WILDLIFE

Most of my attention has been given to ruffed grouse-aspen relationships. Due to their multiple uses of aspen, resulting in a need for access to more than one age class, it is more difficult to meet the needs of ruffed grouse than that of any other species of wildlife living among the aspens. Among the wildlife using aspen, ruffed grouse are the last to respond to management designed for their benefit.

A study of song-bird response to aspen management for ruffed grouse at Mille Lacs showed that 16 to 24 species used 2- to 5-year-old regeneration, in contrast to 15 species in unharvested, old, northern hardwood forest (Back 1982). Breeding male song-bird densities were 1.3 to 2.5 times greater in the regeneration than in the old forest. Three years later Fouchi found 21 to 26 species of songbirds in some of the same regeneration plots studied by Back, and 23 species in the old, uncut forest (Fouchi and Gullion 1984). Back (1982) found the greatest species diversity in the 10-acre clearcuts. But all the species found in the larger clearcuts were found in one or more of the 1-acre clearings.

MANAGEMENT CONFLICTS AND CONSTRAINTS

Providing adequate interspersion of age classes is probably the most serious aspen management problem to be confronted where and when ruffed grouse are included as an important benefit. Maximum ruffed grouse densities will be found where at least 1 acre in every 10 is in a young pole stage (2-5" dbh) at densities of 3000 to 8000 stems/acre. This optimum density stand should be within 100 yards of mature, male, catkin-producing aspens.

The best way to achieve this is by harvesting aspen every 10-12 years in small blocks (<10 acres), rotating around a common corner. Any other program or design will result in a hiatus in grouse use until the proper density of young aspen becomes available again.

Elsewhere, in a concurrent session at this symposium, the thinning of aspen to improve its growth is being discussed. Since proper stem densities are a critical factor governing ruffed grouse use of aspen stands, treatments that alter these densities will impact upon ruffed grouse numbers.

Perala (1978) has suggested thinning 10-year-old stands to densities of 2,000 or fewer stems/acre (with 550/acre an optimum density) which would reduce the value of the aspen stand as cover for ruffed grouse. But the thinned stand should retain its value as a source of food. If the thinning resulted in substantially increased understory shrub growth (mostly hazel and/or alder) that stand would be improved as year-long habitat for ruffed grouse since it would provide sufficient cover under aspen that would be producing a winter-long food resource about 14 years after stand regeneration. This treatment may actually prolong the usefulness of the site as grouse cover since the shrub understory will probably provide sufficient cover well beyond the time that natural thinning of the aspen would reduce aspen stem densities below acceptable levels.

Perala and Laidly (1989) have created this apparently favorable situation through a nitrogen-fertilized aspen thinning treatment near Toivola, about 40 miles northwest of Duluth, Minnesota. On this site, visited as a part of this Symposium activities, the understory vegetation in the thinned area provided a quality of grouse habitat judged to be quite superior to that persisting in the nearby unthinned aspen stand.

If the thinning did not result in the development of an adequate understory shrub growth this loss of habitat could probably be avoided by leaving one 1-acre parcel unthinned in each 10 acres. As I have noted earlier, ruffed grouse do not need extensive areas of cover of the proper density, but they appear to need at least one acre in each activity center to provide security. This does not have to be aspen, but aspen cover is clearly preferred. Acceptable densities for alder or even hardwood regeneration are the same as for aspen, but if the shrubs are hazel or species having similar growth form, densities should be 3 to 4 times those given for aspen (Cade and Sousa 1986).

MANAGEMENT APPLICATIONS

The forest manager involved with aspen management can prescribe ruffed grouse abundance for the next two decades, or longer, by how he or she plans aspen harvesting and subsequent treatments. More than a quarter-century of experimentation and documented aspen response shows that this can be done with a high level of confidence, at least in Minnesota forests.

While various embellishments can be incorporated to satisfy various aesthetic needs, the basic factors are proper-sized clearcuts interspersed in space and time to continually provide critical food and cover within acceptable foraging distances.

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NONGAME RESPONSE TO RUFFED GROUSE HABITAT MANAGEMENT IN PENNSYLVANIA

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ABSTRACT.--I examined abundance and distribution of bird and small mammal communities associated with 1-ha even-aged stands in aspen (Populus spp.) and mixed-oak (Quercus spp.) cover type that were managed for ruffed grouse (Bonasa umbellus) habitat in central Pennsylvania from 1981 to 1986. Birds and small mammals adapted to edge or brushy habitats created by clearcutting were generally abundant on the study area. Based on studies to date, habitat management for grouse had no apparent negative effect on abundance and distribution of nongame wildlife. However, greater amounts of edge created by grouse management may have a negative impact on avian nesting success. Snags, rough-barked overstory trees, and slash should be retained in managed stands for the benefit of wildlife.

INTRODUCTION

Wildlife managers generally have assumed in the past that habitat management for a game species has an indirect yet beneficial effect on coexisting nongame species (Yahner 1989). However, information on the impact of habitat management for a game species on coexisting species is scarce because relatively little is known about the habitat requirements of many nongame wildlife species (Robbins 1978, Zagata 1978). More attention must be given to the impact of habitat management for a game species on nongame because the future credibility of the wildlife profession is under question by some anti-hunting groups (e.g., Friends of Animals, Inc., National Shooting Sports Foundation 1973), who are concerned that wildlife managers are managing habitat for game species with little or no regard for nongame species.

The effects of habitat management for forest game wildlife on coexisting nongame wildlife have been well-documented in Minnesota (Mille Lacs Wildlife Management Area) and Pennsylvania (Barrens Grouse Habitat Management Study Area). On both areas, forest stands have been managed using an even-aged system of forest clearcutting to determine its effect on distribution and abundance of ruffed grouse (Gullion 1976, 1983, Liscinsky and Claffey 1979, Back 1982). In this paper, my objective is to summarize the effects of forest habitat management for ruffed grouse on coexisting nongame species at the Barrens Grouse Habitat Management Study Area.

STUDY AREA

The Barrens Grouse Habitat Management Area (BGMA) was established on State Game Lands 176, Centre County, Pennsylvania, in 1975 under the supervision of the Pennsylvania Game Commission. The BGMA is 1,166 ha and contains two cover types: aspen and mixed-oak. Principal canopy trees in aspen type are bigtooth aspen (Populus grandidentata), quaking aspen (P. tremuloides), and pitch pine

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(Pinus rigida). Predominant canopy trees in mixed-oak are white oak (Quercus alba), northern red oak (Q. rubra), chestnut oak (Q. prinus), scarlet oak (Q. coccinea), and red maple (Acer rubrum) (Yahner and Grimm 1984, Yahner 1986a).

The BGMA is divided equally into a control and a treated sector. Uncut forest on both control and treated sectors has not been clearcut for 60-65 years, whereas the treated sector has been managed using an even-aged system of forest clearcutting. The treated sector of the BGMA consists of a checkerboard pattern of 136 contiguous 4-ha square blocks, with each block divided into four 1-ha (100 x 100 m) stands, which represents an activity center for an adult grouse (see Gullion 1972). Sixty and 76 blocks, or activity centers, are in aspen and mixed-oak, respectively.

Gullion (1972, 1977) recommends that each activity center in aspen type should include stands of three age classes. A portion of an activity center should be a younger (< 10 years old) stand of suckers and saplings for use by grouse broods as cover and feeding sites, an intermediate-aged (10-25 years old) stand for wintering and breeding cover, and an older (25-40 years old) stand for winter feeding sites (Gullion 1972, 1977). Thus, at the BGMA, the western 1-ha stand in each block was cut in winter 1976-77 (first cutting cycle), and the 1-ha northern stand in aspen cover type only was cut in winter 1980-81 (second cycle). The remaining portion of each block was uncut, giving three age classes in aspen and two in mixed-oak type. At the completion of the second cycle, 36 percent of the forest in the treated sector (50 percent in aspen, 25 percent in mixed-oak) was clearcut (Yahner 1986a, Yahner and Scott 1988). A third cutting cycle occurred at the BGMA from winters 1985-86 to 1987-88, which removed eastern and northern stands in aspen and mixed-oak blocks, respectively. However, in this paper, I report only responses of nongame wildlife to habitat management resulting from the second cutting cycle; my ongoing research is designed to evaluate nongame responses to the third cycle.

In summary, habitat management at the BGMA has created a mosaic of different-aged forest stands to meet the habitat requirements of ruffed grouse during the annual cycle. Because of differences in age of stands, vegetative structure varies markedly among stands due to natural plant succession. Moreover, the interspersion of many small stands of different age has created considerable edge habitat for nongame wildlife.

BREEDING BIRD RESPONSE TO GROUSE MANAGEMENT

During a 1-year study comparing breeding-bird communities between treated and control sectors of the BGMA, I found slightly more species on the treated (n = 36) than the control sector (n = 34) (Yahner 1984). Seven species (blue jay, gray catbird, eastern bluebird, golden-winged warbler, chestnut-sided warbler, ovenbird, and field sparrow; scientific names of fauna in appendix) were more abundant on the treated sector, whereas only red-eyed vireos were more common on the control sector. I concluded from this study, that the extent of horizontal patchiness created by forest clearcutting on the treated sector was responsible for high densities of species adapted to early successional or brushy habitats. Moreover, the degree of forest clearcutting had no negative effect, in terms of densities, on most species generally termed forest-interior specialists.

During an intensive 3-year study, 69 species were noted in spring at the BGMA (Yahner 1986a). Numbers of species were highest in uncut stands in aspen and mixed-oak type on the treated sector (n = 47-51), intermediate in the control sector (n = 43) and in older clearcut stands (western) of both types (n = 30-35), and lowest in younger clearcut stands (northern) in aspen type (n = 16). However, total abundance of breeding birds, expressed as the number contacted/10 ha of all species combined, was highest in uncut stands on the treated sector on in older clearcut stands on the treated sector (35.0-54.4/10 ha), intermediate on the control sector (28.1/10 ha), and lowest in younger clearcut stands on the treated sector (21.5/10 ha). Bird species characteristic of clearcut stands at the BGMA were principally those that foraged and nested in dense shrubby vegetation near ground level, such as gray catbirds and chestnut-sided warblers (Table 1). In contrast, species that foraged on tree trunks or in canopies of overstory trees, e.g., black-capped chickadees and red-eyed vireos, were found typically in uncut stands on both treated and control sectors.

WINTERING BIRD RESPONSE TO GROUSE MANAGEMENT

As in the breeding season, the number of bird species during winter at the BGMA was higher on the treated sector (n = 16) than on the control sector (n = 14) of the BGMA (Yahner 1985). Abundance of wintering birds of all species combined was comparable between sectors (control: 10.8/20 ha, treated: 10.1/20 ha). Perhaps because wintering birds generally consisted of highly mobile, interspecific flocks, habitat use of even-aged stands appeared to be less specific in winter than that of breeding species.

Numbers of species in even-aged stands were considerably lower during winter than the breeding season. For instance, I found only 13 wintering species at the BGMA during a 3-year study (Yahner 1986a). Compared to the breeding season, numbers of wintering species were low (n = 5-9) in even-aged stands, particularly in the youngest clearcut (n = 1). Trunk-bark foraging species, such as black-capped chickadees and downy woodpeckers, predominated during winter at the BGMA (Table 1).

SMALL MAMMAL RESPONSE TO GROUSE MANAGEMENT

Number of small mammals live-trapped on the control sector (n = 4) were comparable to numbers trapped in different-aged stands on the treated sector (n = 4-6) at the BGMA during summer (Yahner 1988a). However, species diversity of small mammals was higher in clearcut stands (H'= 1.20-1.41) than in uncut stands on either sector (H' = 0.72-1.05).

The three most common small mammals at the BGMA were masked shrews, southern red-backed voles, and white-footed mice (Yahner 1988a). Masked shrews were more common in both clearcut and uncut stands on the treated sector (1.1-1.5 individuals captured/100 trapnights) compared to the control sector (0.5/100 trapnights). Southern red-backed voles were not captured on the control sector but were more

Table 1.--Common breeding and wintering birds in clearcut stands on the treated sector versus uncut stands on both treated and control sectors of the BGMA, Centre County, Pennsylvania (Yahner 1986a, 1987a).

	Clearcut Stands	Uncut Stands
Breeding Birds:	Gray catbird	Blue jay
	Golden-winged warbler	Black-capped chickadee
	Chestnut-sided warbler	Red-eyed vireo
	Common yellowthroat	Black-and-white warbler
	Indigo bunting	Ovenbird
	Rufous-sided towhee	Rufous-sided towhee
	Field sparrow	
Wintering Birds:		Downy woodpecker
		Black-capped chickadee
		White-breasted nuthatch

abundant in clearcut (0.9-1.0/100 trapnights) than in uncut stands (0.4-0.7/100 trapnights). White-footed mice, on the other hand, predominated in uncut stands on both sectors (2.5-3.0/100 trapnights) rather than in clearcut stands (0.3-1.0/100 trapnights).

CHARACTERISTICS OF STANDS AND MANAGEMENT RECOMMENDATIONS

Differences in abundance and distribution of nongame wildlife in habitat managed for ruffed grouse are attributed partially to characteristics of even-aged stands. These characteristics include size of stands, amount of edge resulting from clearcutting, changes in vegetative structure of stands due to succession, and amount of residual overstory trees, snags, and slash remaining in stands subsequent to clearcutting.

EFFECTS OF CLEARCUT SIZE

The number of wildlife species in a given area generally increases with habitat size (e.g., Forman et al. 1976, Yahner 1983a, 1983b, Buckner and Shure 1985). Yet the controversy over whether one large clearcut stand is more beneficial to wildlife compared to many small clearcuts is not unresolved. Based on limited evidence, Conner et al. (1979) suggested that clearcut stands in Texas should be 12-16 ha for breeding songbirds, and Scott (1986) suggested that clearcut stands in northern Pennsylvania should be at least 15-20 ha for snowshoe hares. With continued clearcutting of habitat for ruffed grouse, the extent of uncut habitat available for breeding bird species requiring large territories may be insufficient for establishment of territories (e.g., Yahner 1988b).

At the BGMA, I found that 1-ha clearcut stands were of adequate size for placement of territories by several edge species, e.g., gray catbirds and common yellowthroats (Yahner 1987a). In addition, uncut stands on the treated sector of the BGMA contained territories of several forest-interior species, e.g., red-eyed vireos and ovenbirds (Yahner 1986a), which are typically characterized as being sensitive to increased forest fragmentation (Whitcomb et al. 1981).

Because interspecific flocks of wintering birds at the BGMA were wide-ranging and used both uncut and older clearcut stands in their daily activities (Yahner 1985, 1987a) and because wintering bird communities may be less sensitive than breeding bird communities to forest fragmentation resulting from forest clearcutting for grouse habitat (Yahner 1985), I suspect that size of clearcut stands is not as critical to distribution and abundance of wintering birds as compared to breeding birds.

Wildlife biologists and conservation biologists have expressed recent concerns with issues ranging from maintenance of minimum viable populations of key species (Reed et al. 1986) to effects of habitat size on rates of predation and parasitism of avian nests (Whitcomb et al. 1981, Wilcove 1985, Small and Hunter 1988). Thus, we must give more consideration to what effects clearcut size have on abundance, distribution, survival, and productivity of wildlife.

EFFECTS OF THE AMOUNT OF EDGE

The mosaic of small clearcut stands at the BGMA provided abundant edge habitat (Yahner 1984). Gray catbirds, chestnut-sided warblers, rufous-sided towhees, indigo buntings, and brown-headed cowbirds used edges of stands more often than interiors (> 25 m from the interface) of stands (Yahner 1987a). Conversely, certain species, e.g., field sparrows, used edges and interiors of stands in proportion to availability. White-footed mice, a small mammal typical of mature forests, avoided edges of uncut stands proximal to clearcut stands but used interiors of uncut stands much more often than expected (Yahner 1986b).

Although diversity and abundance of wildlife often are greater near edges than away from edges, greater amounts of edge habitat may have a detrimental effect on avian productivity (see Yahner 1988b). Nest parasitism and predation may increase with greater amounts of edge (e.g., Whitcomb et al. 1981, Brittingham and Temple 1983). For instance, we have shown at the BGMA that 68 percent of the artificial avian nests placed in aspen cover type with greater amounts of edge (50 percent forest clearcutting) on the treated sector were destroyed by predators compared to 19 percent in oak type (25 percent forest clearcutting) on the treated sector or 9 percent on the control sector (Yahner and Scott 1988). Predation on nests at the BGMA increased with greater amounts of edges because avian nest predators adapted to edge conditions, such as American crows and blue jays (Whitcomb et al. 1981, Wilcove 1985), increased on the treated sector (Yahner and Scott 1988). However, rates of predation on avian nests did not vary along junctions of clearcut and uncut stands that differed in time since clearcutting (Yahner et al. 1989).

EFFECTS OF VEGETATIVE STRUCTURE

Natural succession resulted in a changing plant community over time at the BGMA. As plant communities changed, succession also occurred in avian communities during three consecutive breeding seasons at the BGMA (Yahner 1986a, 1987b). Field sparrows were common in younger stands in aspen type, but gray catbirds, golden-winged warblers, and chestnut-sided warblers preferred older clearcut stands. Common yellowthroats were abundant in all clearcut stands, whereas rufous-sided towhees were common in all stands on the treated sector except in the youngest clearcut stands. Compared to the breeding season, only the black-capped chickadee occurred in young stands (2-4 years old) during winter at the BGMA (Yahner 1986a). Younger stands, which are characterized by reduced plant succession and less vertical stratification of vegetation, provide less food and cover and have less suitable microenvironments compared to older clearcut stands for wintering birds (Yahner 1987a, see also Petit 1989).

Although young clearcut stands have reduced vertical stratification of vegetation, these stands typically contain a dense mat of seedlings and saplings near ground level (Yahner and Grimm 1984). Dense vegetation near ground level not only conceals nests but simultaneously reduces the foraging efficiency of predators (e.g., Bowman and Harris 1980). At the BGMA, we noted that artificial nests placed low to ground level (0.5 m above ground) in 4-year-old clearcut stands were much less susceptible to disturbance by predators than nests located at either 0.5 or 1.5 m above ground in 8-year-old stands with less dense vegetation (Yahner and Cypher 1987).

Masked shrews were relatively ubiquitous in use of stands at the BGMA, whereas southern red-backed voles occurred almost exclusively in clearcut stands with dense vegetation near ground level, which presumably provided moist microhabitats (Yahner 1988a). Red-backed voles were selective in microhabitats with high moisture requirements because of its intolerance of dry conditions (Gunderson 1959). The most common small mammal in uncut stands was the white-footed mouse; this species relies on woody vegetation as foraging and nest sites (Yahner 1986c, 1988a).

EFFECTS OF RESIDUAL FEATURES IN CLEARCUT STANDS

Snags, live overstory trees, and slash are important residual features that can have a major affect on abundance and distribution of wildlife using clearcut stands. At the BGMA, densities of snags were correlated with numbers of bird species and with and densities of downy woodpeckers and black-capped chickadees (Yahner 1986a). Snags provide important foraging and nesting sites for many wildlife species in clearcut stands (Dickson et al. 1983, Dessecker and Yahner 1987). Dickson et al. (1983) recommended that a minimum of five snags/ha be left in clearcut stands to maintain breeding populations of cavity-nesting birds, such as great crested flycatchers and downy woodpeckers. Retention of snags can have a profound positive effect on the regional distribution of woodpeckers and other cavity-dependent species of wildlife (Galli et al. 1976, Yahner 1983c). The Pennsylvania Game Commission has retained snags in clearcut stands of mixed-oak cover type with the third (1985-87) cutting cycle at the BGMA.

Wintering species of trunk-bark foragers, such as downy woodpeckers and black-capped chickadees, foraged more often than expected on rough-barked trees (e.g., Quercus or Pinus) than on smooth-barked trees (e.g., Populus) at the BGMA (Yahner 1987a). Overstory trees with rough or flaky bark contain abundant refugia for arthropods in bark crevices and, hence, are important foraging substrate for wildlife (Brawn et al. 1982). In addition, red squirrels, which typically occur in northern coniferous forests (Rusch and Reeder 1978), were very dependent on cone seeds of pitch pine as a food source at the BGMA (Yahner 1987c).

Overstory live trees and large snags provide perch sites for birds in clearcut stands (Back 1982). Based on convincing unpublished data collected since the third cutting cycle at the BGMA, I have found that various bird species (e.g., northern orioles, hairy woodpeckers) would not use recent clearcut stands were it not for the retention of overstory trees and snags in these stands. Dickson et al. (1983) also noted that large trees in clearcut stands were important as song perches for many bird species, e.g., summer tanagers, black-and-white warblers, blue jays, and brown-headed cowbirds.

Slash left ground level after clearcutting can be valuable as cover and foraging sites for wildlife (Hassinger et al. 1975). At the BGMA, slash was used by gray catbirds, common yellowthroats, rufous-sided towhees, and field sparrows as foraging and perching sites significantly more than expected (Yahner 1987a). Densities of logs (e.g., slash) in clearcut stands, which provided refugia and foraging sites for small mammals, were directly correlated with numbers of species of small mammals at the BGMA (Yahner 1986c, 1988a). The amount of slash in clearcut stands also important as cover for snowshoe hares in northern hardwood clearcut stands (Scott and Yahner 1990). Thus, I recommend that slash, rough-barked overstory trees, and snags are important residual features that should be retained in clearcut stands for the benefit of wildlife (Yahner 1987a).

CONCLUSIONS

More attention should be given to the effects of habitat management for ruffed grouse on coexisting species. Based on my studies to date in central Pennsylvania, habitat management for grouse generally has been beneficial to nongame wildlife adapted to early successional habitats, such as clearcut stands. However, because habitat management for grouse increases the amount of edge, avian nesting success may be reduced due to greater incidences of nest predation and parasitism. Wildlife managers and land managers should ensure that residual features, such as snags, rough-barked trees, and slash, should be retained in managed stands for the benefit of wildlife. In addition, I recommend that future studies should focus on what effects size and shape of stands managed for grouse habitat have on abundance and distribution of nongame wildlife.

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APPENDIX

Common and scientific names of birds and mammals mentioned in text and tables.

	Common Name	Scientific Name
Birds:	Ruffed grouse	Bonasa umbellus
	Hairy woodpecker	Picoides villosus
	Downy woodpecker	Picoides pubescens
	Great crested flycatcher	Myiarchus crinitus
	Blue jay	Cyanocitta cristata
	American crow	Corvus brachyrhynchos
	Black-capped chickadee	Parus atricapillus
	Eastern bluebird	Sialis sialis
	Gray catbird	Dumetella carolinesis
	Red-eyed vireo	Vireo olivaceus
	Black-and-white warbler	Mniotilta varia
	Golden-winged warbler	Vermivora chrysoptera
	Chestnut-sided warbler	Dendroica pensylvanica
	Ovenbird	Seiurus aurocapillus
	Common yellowthroat	Geothlypis trichas
	Northern oriole	Icterus galbula
	Brown-headed cowbird	Molothrus ater
	Summer tanager	Piranga rubra
	Indigo bunting	Passerina cyanea
	Rufous-sided towhee	Pipilo erythrophthalmus
	Field sparrow	Spizella pusilla
Mammals:	Masked shrew	Sorex cinereus
	Red squirrel	Tamiasciurus hudsonicus
	Snowshoe hare	Lepus americanus
	White-footed mouse	Peromyscus leucopus
	Southern red-backed vole	Clethrionomys gapperi

HYBRID POPLAR PRODUCTIVITY AND SUITABILITY FOR THE FOREST TENT CATERPILLAR: A FRAMEWORK FOR EVALUATION

D.J. Robison and K.F. Raffa[1]

ABSTRACT.-- Fifteen hybrid poplar, Populus spp., clones were evaluated for growth, tolerance to defoliation, and suitability for the forest tent caterpillar, Malacosoma disstria. Poplar clones were ranked according to their suitability for M. disstria, as indicated by behavioral and developmental bioassays. Patterns of poplar growth characteristics and M. disstria preference and performance among the 15 clones were used to construct a productivity - suitability matrix. This matrix provides a framework for evaluating insect pest resistance in selected poplar clones and for considering clonal contributions to poplar-M. disstria interactions. The matrix concept and design incorporates both biologically and economically important criteria, and may facilitate similar evaluations for other important pests and crops.

INTRODUCTION

The potential value of woody biomass crops for multiple uses has fostered research and development with hybrid poplar. In northern North America, hybrids and selections within the genus Populus possess desirable characteristics and growth potential for short rotation intensive culture forest systems (Dickman and Stuart 1983). Knowledge of the silvics of the genus and appropriate silvicultural techniques has steadily advanced. However, the development of scientific theory and evaluation strategies to appropriately transfer these new technologies into biologically and economically acceptable practice has lagged. One area in which such evaluation strategies are needed is in the development and utilization of genetically based resistance to insects.

Insects on planted poplars have been cataloged, and several species including the cottonwood leaf beetle, Chrysomela scripta Fab., tarnished plant bug, Lygus lineolaris (Palisot de Beavois), and poplar-and-willow borer, Cryptorhynchus lapathi (L.), have become pestiferous (Moore and Wilson 1983). Dickman and Stuart (1983) report 24 insect species as major pests of Populus, and Moore and Wilson (1983) state that as many as 150 species are potentially injurious. While there is some tendency to consider insect damage as inevitable or to rely exclusively on traditional insecticidal control, there is also evidence of differential resistance among poplar clones (Abrahamson et al. 1990, Caldbeck et al. 1978, Harrell et al. 1981, Wilson and Moore 1985, 1986). This evidence, coupled with knowledge of plant defensive chemistry (Feeny 1976, Palo 1984), physiological balance between plant defenses and plant productivity (Bazzaz et al. 1987, Bryant et al. 1985, Loehle and Namkoong 1987), and research on resource utilization by poplar feeding insects (Bryant et al. 1987, Lindroth et al. 1988), suggests that natural resistance could potentially be enhanced to economically significant levels. Additionally, poplars have been targeted with some success for genetic improvement through the insertion of novel genes (Fillatti et al. 1986, Klopfenstein et al. 1989).

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The development and utilization of hybrid poplar clones resistant to insects depends upon many factors. Planting and silvicultural strategies need to consider the number and arrangement of clones, the size of clonal blocks (Burdon 1982, Heybroek 1984, Libby 1982), spacing, rotation age, number of coppice rotations expected, and site productivity and accessibility (Bowersox and Ward 1977, Dickman and Stuart 1983). Insect related considerations include behavioral and physiological characteristics, such as feeding guild, phenology, capacity for population growth, and susceptibility to insecticides. Tree improvement efforts demand knowledge of plant genetics, reproduction, tissue culture and genetic manipulation (McCown 1985, Zobel and Talbert 1984).

The integration of these factors will facilitate a comprehensive approach to insect pest management. Transferring information from laboratory, greenhouse and field experiments to production plantations poses many challenges to the successful utilization of plant-insect interaction theory and findings. The current study attempts to approach these challenges in a comprehensive manner and develop a preliminary framework for evaluating hybrid poplar-insect pest interactions, using the forest tent caterpillar, Malacosoma disstria Hbn.(Lepidoptera: Lasiocampidae), as a study insect.

This insect is an oligophagous, univoltine, early season defoliator; features shared with a number of important Lepidopteran forest pests. In north central North America it is often associated with the aspens, Populus tremuloides Michx. and P. grandidentata Michx., and undergoes periodic outbreaks lasting four to six years every six to 16 years (Batzer and Morris 1971, Hodson 1941). Recently M. disstria was reported as a serious pest in a hybrid poplar research plantation[2], indicating that production plantations are at risk. Accordingly, the hybrid poplar-M. disstria association is both a useful model system and of economic importance.

Entomological and plant production factors must be considered in evaluating resistance (Painter 1941). Tree survival, growth rate, growth form, and tolerance to damage are important forest production considerations. Ecologically, the insect's behavioral and developmental responses to host plants, plant responses to insect pressures, and the influence of cultural conditions on pest biology, must be evaluated. In the M. disstria-poplar association, key areas of focus are adult ovipositional and larval feeding preference, larval performance, and capacity for population increase. Clonal tolerance to defoliation and inherent growth rate of the various clones are important plant variables. In the current study these parameters were evaluated individually, and then analyzed collectively to appraise how various factors might be manipulated to advance pest management through resistant clones.

EXPERIMENTAL APPROACH

Fifteen clones of hybrid poplar were selected to represent a broad taxonomic background and to maximize the probability of obtaining differential susceptibility to M. disstria (Table 1). Included among these selections were clones from the Leuce (aspens), Aigeiros (cottonwoods) and Tacamahaca (balsam poplars) sections of the genus Populus. Poplars were established from dormant hardwood cuttings in plastic pots in a glasshouse on the University of Wisconsin-Madison campus. Malacosoma disstria were obtained in 1988 as overwintering 1st instar larvae in eggs on aspens from outbreak populations on the Menominee Indian Reservation, Keshena, WI. All experimental insects were reared on foliage from glasshouse-grown poplar clones or on artificial diet (Grisdale 1985).

The following questions were addressed: 1) To what degree does M. disstria preference and performance vary among selected poplar clones? 2) What are the relative growth rates and foliar characteristics among the clones? 3) What are the relationships between poplar clones and their suitability for M. disstria? In conjunction with these questions, several ecological and silvicultural implications were addressed to help develop a framework for evaluation: 1) What are the relationships

[2]E.A. Hanson, USDA For. Serv., No-Central For. Exp. Stn., Grand Rapids, MN; pers. comm. 1989.

Table 1.--Populus spp. clones evaluated.[1]

NC[2] No.	NE[2] No.	Other Name	Parentage[3]
5339	-	Crandon	alba x grandidentata
5260	-	Tristis #1	tristis x balsamifera
11505	388 & 88	-	maximowiczii x trichocarpa
5271	19	-	nigra Chark. x nigra Caud.
11004	-	Siouxland	deltoides x deltoides
5377	-	Wisc. #5	deltoides x nigra
11382	27	-	nigra Chark. x berolinensis
11396	49	-	maximowiczii x berolinensis
11445	280 & 157	-	nigra x laurifolia
5331	299	-	nigra Betulifolia x tricho.
11432	252	-	deltoides Angulata x tricho.
-	332	-	simonii x berolinensis
-	-	NM6	nigra x maximowiczii
-	-	DTAC2	deltoides Ang. x berolin.
5262	387	-	balsam. subcord-Cand. x berolin.

[1]Clonal material provided by: USDA North Central For. Exp. Stn., Rhinelander, WI; SUNY College of ESF, Syracuse, NY; and OMNR Fast Growing Forests Group, Brockville, ONT.

[2]NC and NE denote clonal designations by the USDA North Central For. Exp. Stn., and USDA No-Eastern For. Exp. Stn., respectively.

[3]All Populus spp. crosses.

between M. disstria host preference and larval performance? 2) How are patterns of poplar clonal growth, resistance and tolerance to defoliation, and M. disstria behavioral and developmental characteristics related? 3) How can information from these analyses be used to evaluate and develop more productive poplar clones?

METHODS

Foliar analysis was standardized for leaf position. Leaf number (position) was assigned by counting down from the most recent unfolded leaf (No. 1). Foliar nitrogen concentration and moisture content were determined from a composite sample of leaves 4, 5 and 6, by micro-Kjeldahl analysis and wet weight/dry weight analyses, respectively. Leaf toughness was measured as grams of force necessary to puncture the leaf surface with a penetrometer, for leaves 3-4 and 7-8.

Larval preference among the 15 clones was evaluated in petri dish bioassays. Each dish contained an excised leaf disk from each clone. Six 2nd instar or four 4th instar larvae were allowed to feed for 24 or 18 hours, respectively. At the end of the feeding period, the area of each leaf disk consumed was estimated by a dot grid method and preference expressed as the percent of leaf disk consumed. Total feeding per dish was used as a covariate in the analysis.

Preliminary investigations into adult M. disstria oviposition preference among the clones were conducted in $1m^3$ cages containing a single plant of each clone. Thirty or 60 female pupae and an equal number of male pupae were introduced into each cage. Moths were allowed to eclose, mate and oviposit, and preference was evaluated by counting the number of egg bands on each clone. Statistical analyses were not conducted.

M. disstria performance was evaluated under controlled conditions (laboratory) and in an open-air glasshouse. In the laboratory 10 first instar larvae were introduced into plastic rearing boxes containing excised whole leaves from specific clones. Larvae were allowed to develop, and performance was measured as development time to pupation, and female pupal fresh weight and width. In the glasshouse, a single egg band containing 60 to 80 eggs was hung within cages containing three plants of the same clone. All eggs hatched within 24 hours of each other. After 14 days of feeding, approximately 20 larvae were removed from each cage and weighed.

Clonal tolerance to loss of photosynthetic area was measured by artificially defoliating plants over a 30 day period. This approximates the natural rate of insect feeding (Hodson 1941). Height growth of control and defoliated plants were measured 10 days after the final treatment, and tolerance computed as the percent growth of defoliated trees, to control trees. Initial height was used as a covariate in the analysis.

Statistical analyses among clones were conducted by the General Linear Models (ANOVA) procedure, and among measured variables Pearson product-moment correlations were calculated (SAS 1982).

RESULTS

Height growth varied significantly among clones after three and a half months, and ranged from 60 to 140 cm (alpha=.05). Foliar nitrogen (2.4 to 4.2 %), moisture (75 to 82 %) and leaf toughness also varied significantly among clones (alpha=.05). Foliar toughness was significantly different among clones for both leaf positions tested.

Feeding preference by 2nd instar larvae varied significantly among clones, ranging from 0.6 to 43.9 percent consumption of leaf disks (alpha=.05). Fourth instar preference also varied significantly among clones, ranging from 11.1 to 50.7 percent leaf disk consumption (alpha=.05). These two behavioral measures, however, were not significantly correlated with each other.

Preliminary investigations on adult M. disstria oviposition have indicated that clonal preferences may exist. However, in these glasshouse bioassays many females failed to oviposit and so more conducive experimental conditions need to be devised. Further studies are underway to develop more sensitive adult bioassay techniques and to test for preferential differences among clones.

In laboratory performance bioassays, M. disstria development varied significantly among clones (alpha=.05). Development time ranged from 31 to 52 days, female pupal width ranged from 5.8 to 8.3 mm, and female pupal fresh weight ranged from 165 to 477 mg, among clones. In glasshouse performance bioassays, larval fresh weights varied greatly among clones (0.88 to 59.83 mg) (alpha=.05), with three clones, DTAC2, NM6 and NC5339 being rejected by the larvae.

Significant differences among clones in tolerance to artificial defoliation were found (65 to 98 % tolerance) (alpha=.05).

DISCUSSION AND FRAMEWORK DEVELOPMENT

Plant hosts which foster larger and more rapidly developing insects, particularly if selectively preferred, are likely to contribute to increasing insect populations and damage. Plant defense (resource availability) theory suggests that the impact of insect pressures depends in part on a physiological balance among plant defenses, reproductive effort and productivity (Bazzaz et al. 1987, Bryant et al. 1985, Loehle and Namkoong 1987). These factors are environmentally mediated, with defenses being both constitutive and induced, and productivity being a combination of inherent growth rate (a species or varietal characteristic), tolerance to loss of photosynthetic area, carbon and nutrient allocation amongst plant parts, and site productivity. These factors coupled with plant age, previous history and cultural conditions contribute to overall plant resistance to pests. Thus the coupling of heritable pest resistance with production forestry objectives requires consideration of the type and intensity of the resistance mechanism, and its relationship with plant productivity. Additionally, the integration of improved genetic pest resistance with production values requires that ecological considerations such as pest biotype evolution, secondary pests, effects on natural enemies and resistance stability, be addressed (Painter 1941, Raffa 1989).

The current study revealed that correlations among the insect preference and performance variables were rare. Only a single significant (non-trivial) relationship, between 2nd instar larval preference and laboratory reared female pupal performance (weight, width) (r=.60, alpha=.1), was observed. Thus various measures of plant suitability for a particular insect are not necessarily related, signaling the need for caution in the use of single factor evaluations of clonal resistance to insects.

Correlations among the plant and insect characteristics measured indicated that foliar nitrogen and toughness were not significantly related to any measure of insect preference or performance (alpha=.1). Foliar moisture content was moderately correlated with 2nd instar preference (r=.5, alpha=.1). Other foliar characteristics, such as phenolic glycosides and other allelochemicals may be important (Bingaman and Hart 1989, Bryant et al. 1987, Lindroth et al. 1986).

Clonal growth rates were not significantly correlated with any measure of insect preference or performance (alpha=.1). The absence of any apparent direct tradeoff between growth and resistance contradicts some aspects of the resource availability hypothesis (Bryant et al. 1985).

Because individual parameters of insect preference or performance were of little value in denoting levels of clonal resistance, and because there were no simple relationships between plant and insect characteristics, a suite of traits must be considered. Such an analysis can be unwieldy, and so a systematic way of examining several factors together is needed. A matrix analysis provides an efficient tool for such an evaluation.

Figure 1 illustrates a proposed Productivity - Suitability Matrix for evaluating plant-insect interactions. Clones can be evaluated for productivity and suitability for insects, and potential directions of tree improvement considered. For example, in Figure 1 clones NC5271 and NM6 are both productive and tolerant of defoliation. However, NM6 is resistant to M. disstria while NC5271 is susceptible. This suggests that pest resistance improvement be a priority for NC5271, but not necessarily for NM6. Thus the matrix facilitates an examination of clonal characteristics, and the relative advantages and disadvantages of improving plants already resistant to insects, versus those which are susceptible. This same approach may also help guide decisions as to whether improvement should strive for additive, synergistic or novel mechanisms of resistance, and what physiological or growth costs are acceptable.

From the 15 clones studied, clones with both high and low suitability for M. disstria corresponding to various portions of the height growth - tolerance to defoliation matrix were identified. Clones listed in Figure 1 have been positioned in a relative fashion, but could be placed quantitatively, and a response surface generated by developing a 3rd axis to represent plant suitability for the insect. Alternative and/or additional plant and insect characteristics could be incorporated into the matrix. The framework permits an evaluation of each clone's relative characteristics in regard to productivity and resistance

High Tolerance	-------TOLERANCE TO DEFOLIATION------	Low Tolerance
High Growth	NC5271 (S,S) NM6 (R,R)	?	NC11004 (S,S)
-	NC11432 (R,i)	DTAC2 (i,R)	NC11396 (i,i)
HEIGHT GROWTH		NC11445 (R,i) NC11382 (S,i) NC5331 (i,R)	NC5377 (S,S)
Low Growth	NC5262 (R,i) NC11505 (i,R)	?	?

Location of clones refers to height growth and defoliation tolerance characteristics. Letters in parentheses following clonal designations refer to M. disstria preference and performance results, respectively; R=resistant, S=susceptible, i=intermediate. A question mark indicates where no clone was found with this combination of traits.

Figure 1.--Productivity-suitability matrix for the hybrid poplar-M. disstria association.

to M. disstria. A generalized pest guild matrix, or a suite of matrices could be used to consider the interactions between several pests and a particular crop. The identification of primary pests, silvicultural objectives and ecological implications, coupled with use of a productivity - suitability matrix, provides a rational approach for integrating genetic pest resistance with production objectives.

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THE RELATIONSHIP OF SITE FACTORS TO THE INCIDENCE OF CYTOSPORA AND SEPTORIA CANKERS AND POPLAR AND WILLOW BORER IN HYBRID POPLAR PLANTATIONS

Gashawbeza Abebe and John H. Hart[1]

ABSTRACT.--Two hybrid poplar plantations in Michigan were surveyed (1984-87) for the incidence of poplar and willow borer damage, and for Cytospora and Septoria cankers. Tree height, root development, disease incidence and clonal differences were measured. Soil samples were analyzed for physical and chemical properties. Tree root development and stem height were significantly reduced by the presence of an ortstein layer. Cytospora canker increased as Fe and Al levels in the soil increased and as K levels decreased. Septoria canker incidence increased with increasing levels of P, K and Mg, and as Fe and Al levels decreased. Poplar and willow borer damage increased with increasing P and K levels. The incidence of Septoria canker generally increased as tree height and borer damage increased while Cytospora canker was associated with unfavorable conditions for growth.

Environmental stress is defined as "...any factor capable of producing a potentially injurious strain; stress exerts the most pronounced effect in predisposing plants towards greater susceptibility to facultative parasites, particularly weak or non-aggressive parasites" (Schoeneweiss 1975). Predisposition is defined by Schoeneweiss (1975) as "...the tendency of non-genetic factors, acting prior to infection, to affect the susceptibility of plants to disease." Thus, predisposition implies an effect on the host rather than on the pathogen. Proneness or disposition of the host to disease prior to infection may influence the subsequent establishment and development of a pathogen (Schoeneweiss 1978).

Soil compaction and cementation can arise from "hardpans." Although several types of hardpans, differing in origin, are known, this study was concerned only with ortsteins. According to Simonson (1968), in 1887 Muller was the first person to recognize the layer in which mobile substances had accumulated. Muller called these cemented or partially-cemented B horizons ortsteins. Thus the term ortstein refers to the B horizon and is derived from two German words meaning "stone in place" (Winters and Simonson 1951).

Simonson (1968) reported that ortsteins affect tree growth adversely and are troublesome when the soils are cultivated. Generally the ortsteins in the northern U.S., as well as those in Europe, resemble a conglomerate or concrete in general structure, with the coarse particles cemented together by iron oxides to form hardpan layers (Winters and Simonson 1951). In addition to iron, ortsteins are also rich in aluminum and manganese and are not homogenous in chemical composition (Polskiy 1961). In addition to the chemical heterogeneity, the morphology and color change with different degrees of waterlogging and with the length of time of excessive wetness (Oglenznev 1968). Generally ortstein layers occur from 20 to 70 cm below the ground surface and their depth is not related to relief of the site (Muir 1961).

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OBJECTIVES

The objectives of this study were:

1. To determine if the incidence of Septoria canker, Cytospora canker and poplar and will borer damage was influenced by site factors.

2. To determine if there was a spatial relationship between soil physical and chemical characteristics and the incidence of cankers in the hybrid poplar stands.

METHODS

The study sites were located in Manistee and Mason counties in Michigan, on plantations established by Packaging Corporation of America. The Manistee plantation was established in the spring of 1978 with a mixture of two hybrid poplar clones: NE 47 ad NE 235. NE 47 (P. maximowiczii x [P. x berolinesis] cv. Oxford) is a cross between the Japanese poplar and the natural hybrid Berlin poplar (P. laurifolia x P. nigra). NE 235 (P. deltoides x P. nigra Incrassata) is a hybrid between eastern cottonwood and black poplar (Dickmann and Stuart 1983, Woods 1984). The site was about 1.2 hectares and was initially planted with about 1605 cuttings in 23 rows. The soil was somewhat poorly to poorly drained, and the land had 0 to 2 percent slope. The water table was within 1.25 m from the surface and soil profiles were highly mottled. A cemented layer of ortstein was sometimes observed.

The Mason plantation (1.8 hectares) was established in the spring of 1979 with a mixture of cuttings of clones NE 47, NE 235 and NE 308. NE 308 (P. nigra var. charkowiensis x P. nigra Incrassata) is a cross between two black poplar varieties (Ministry of Natural Resources 1983). Originally 2655 cuttings in 34 rows were planted. The soil was moderately well drained and the land had 0 to 2 percent slope. A discontinuous cemented layer of ortstein was observed.

In 1984 both plantations had conspicuous gaps and open spaces where the trees had died. Tree mortalities from planting (1978 or 1979) to 1984, from 1984 to 1986 and during the summer of 1987 were calculated based on the original planting space of 2.4 x 3 m. Height of every tree at both locations was measured in the summer of 1984 using a telescopic measuring pole. Each tree was identified by clone either as NE 47, NE 235 or NE 308. A t-test was conducted to determine if there was a significant difference in mean of tree heights by study site.

In the summer of 1984 individual trees at both study sites were checked for the presence or absence of Cytospora canker. In the summer of 1986 trees were individually examined and rated for Septoria canker and poplar and willow borer in addition to Cytospora canker. Chi-square (X^2) values were calculated for cankers and borer rating classes to check for independence of site or clone. Further analysis of variance was carried out to determine clone and site interaction. In the 1986 observation both cankers and borer damage were rated using the following scoring scheme:

Rating	Septoria and Cytospora Cankers	Poplar and Willow Borer
1	Absence of canker	No apparent injury
2	Cankers on branches	Frass on the lower 1/3 of tree
3	Cankers on main stems	Frass on the lower 2/3 of tree
4	Main stem dieback tree dead or dying	Frass throughout the tree

Soil sampling was done to determine the distribution, depth and thickness of the ortstein layer in the two study areas. Soil borings one meter deep on transects 10 m apart were made using a soil augur. Samples were taken 10 m apart for 150 m for a total of 15 samples per row. Each soil sample was checked for color, mottling and presence or absence of a cemented ortstein layer. When an ortstein layer was encountered, its depth from the surface and its thickness were noted. Following the above sampling procedure, a total of 180 and 120 sample holes was dug at the Mason and Manistee study sites, respectively.

Nine trees around each ortstein sampling point were identified by clone and were grouped by the presence or absence of an ortstein layer. Average tree heights were compared between the two groups. The relationships between depth to the ortstein layer and tree height, canker incidence, and insect borer damage ratings were investigated.

In summer of 1986 soil samples were taken from both study sites for nutrient content determination; 10 holes at the Mason site and 7 holes at the Manistee site were dug one meter deep. Soil horizons in a profile were differentiated by soil color or texture change as the plow layer (Ap), zone of eluviation (E) or zone of illuviation (B). The B horizon was further grouped as Bhs or as Bs based on the accumulation of organic matter (h) and sesquioxides of iron and aluminum (s). Each horizon depth, thickness and color was recorded. Soil samples from each horizon were tested for pH, nitrate nitrogen (NO_3-N), extractable phosphorus (P), exchangeable cations: calcium (Ca), potassium (K), magnesium (Mg); and exchangeable manganese (Mn), iron (Fe) and aluminum (Al) (Abebe 1988).

Twenty trees around each soil sampling point for nutrient level tests were identified by clone. Possible correlations with soil nutrient levels and tree heights, canker incidence and insect borer ratings were determined. Scheffes multiple range test was used to test for significant differences in nutrient level means between horizons in a profile or between profiles in a study site. All significant differences were indicated at the 0.05 level.

RESULTS

Between 1978-1984, 44 percent of the trees died at the Manistee plantation while 16 percent died at the Mason plantation. By the summer of 1987, 60 percent of the original planted trees at Manistee and 23 percent at Mason were dead.

The original planting at the Mason site was a mixture of clones, where the proportions or the total number of cuttings planted for each clone was unknown. Thus it was not possible to determine mortality rates by clone prior to the 1984 inventory. However, between 1984 and 1987 at the Mason site mortality was 14 percent, 9 percent and 7 percent for clones NE 47, NE 235, and NE 308 respectively, based on 1984 live trees of each clone (Table 1). NE 47 showed 29 percent mortality in 1987 based on 1984 residual live trees at the Manistee site.

Average tree heights for the three clones at the two study sites are shown in Table 2. Although the Mason plantation was one year younger, its trees were taller than those of the Manistee plantation. At t-test of average tree height in 1984 by location showed that trees at the Mason site were significantly taller (4.6 m) than trees at the Manistee site (3.1 m) ($P < 0.01$).

Since all three clones were not planted at both study sites it was not possible to compare the effect of site on all clones. However, since NE 47 was planted at both study sites it was used as a basis to check if there were any differences in pest incidences between the two study sites (Table 3 & 4). At both study sites Cytospora canker was more prevalent on branches than on the main stem of NE 47. However, more stem diebacks (27%) were observed on the trees at Manistee as compared to Mason (2%) (Tables 3 & 4). A chi-square test showed significant difference of Cytospora canker incidence between the two study sites ($P < 0.01$). Septoria canker and borer damage on NE 47 was

Table 1.--Summary of clone mortality between 1984 and 1987.

Clone	Mason			Manistee		
	No. of Live Trees		Percent	No. of Live Trees		Percent
	1984	1987	Mortality	1984	1987	Mortality
NE 47	288	248	13.9	884	623	29.5
NE 235	944	862	8.7	16	14	12.5
NE 308	1008	933	7.4	NOT PLANTED		

Table 2.--Tree heights in 1984 by clone and study site.

Clone	Site	No. of Trees	Ave. Ht. (m)	Std. Error
NE 47	Mason	288	4.5	0.1
	Manistee	884	3.1	0.1
NE 235	Mason	944	4.9	0.1
	Manistee	16	4.2	0.3
NE 308	Mason	1008	4.4	0.1
	Manistee	NOT PLANTED		

Table 3.--Canker and borer rating in 1986 of NE 47 at the Manistee plantation.

Pest Rating	Poplar and Willow Borer		Septoria Canker		Cytospora Canker	
	No. of Trees	%	No. of Trees	%	No. of Trees	%
1	608	98.1	602	97.2	62	10.0
2	7	1.1	9	1.5	393	63.3
3	3	0.5	6	1.0	1	0.2
4	2	0.3	2	0.3	164	26.5

more prevalent at the Mason site than at the Manistee site. A Chi-square test showed significant difference ($P < 0.01$) in borer damage between the two study sites.

At the Manistee plantation Cytospora canker was more prevalent than Septoria canker and poplar willow borer damage (Table 3). The slow-growing trees (Table 2) at the Manistee plantation were more susceptible to the nonaggressive facultative parasite Cytospora chrysosperma than to the aggressive Septoria musiva.

Table 4.--Canker and borer rating by clone in 1986 at the Mason plantation.

	NE 47		NE 235		NE 308	
Borer Rating	No. of Trees	%	No. of Trees	%	No. of Trees	%
			--- Poplar and Willow Borer ---			
1	194	78.2	26	3.0	298	31.9
2	19	7.7	36	4.2	97	10.4
3	33	13.3	770	89.3	374	40.1
4	2	0.8	30	3.5	164	17.6
			--- Septoria Canker ---			
1	13	5.2	24	2.8	179	19.2
2	8	3.2	23	2.7	105	11.3
3	16	6.5	34	3.9	575	61.6
4	211	85.1	781	90.6	74	7.9
			--- Cytospora Canker ---			
1	76	30.6	754	87.5	913	97.9
2	168	67.7	102	11.8	18	1.9
3	0	0.0	2	0.2	1	0.1
4	4	1.6	4	0.5	1	0.1

At Mason 22 percent, 68 percent and 97 percent of the NE 47, NE 308 and NE 235 trees, respectively, were attacked by the borer (Table 4). In Ontario, Canada, three-year-old NE 47 plantations showed no infestation by poplar and willow borer, while NE 308 was infested 31 percent to 51 percent (Morris 1980). Septoria canker and borer damage to NE 235 and NE 308 at the Mason plantation (both high, Table 4) and to NE 47 at the Manistee plantation (both low, Table 3) were closely related. The insect was probably serving as an infection point for Septoria musiva (Moore 1984).

At the Mason study site 71 (39%) of the 180 borings and at the Manistee site 52 (43%) of the 120 borings showed an ortstein layer. The distribution of the ortstein layer was discontinuous in both sites. Comparison (Table 5) between the two sites showed that there was no significant difference in the beginning (minimum depth) of the ortstein layer ($p > 0.05$), while significant differences were found in the maximum depth of the ortstein layer ($P < 0.05$) and the ortstein layer thickness ($P < 0.05$).

The average height for trees in the presence of an ortstein layer at Manistee was 3 m while it was 3.1 m in the absence of an ortstein layer (no significant differences at $P = 0.05$). At Mason, however, there was a significant difference between the average height for trees growing in the absence of an ortstein layer (4.8 m) compared to 3.6 m for trees where an ortstein layer was present.

Table 5.--Ortstein layer depth and thickness comparison between the two study sites.

Site	Profiles with Ortstein	Min Depth Mean	Min Depth Std. Error	Max. Depth Mean	Max. Depth Std. Error	Ortstein Thickness Mean	Ortstein Thickness Std. Error
Manistee	52	33.1a[1]	1.8	67.0a	3.0	33.8a	2.8
Mason	71	34.8a	1.9	75.3b	2.2	40.5b	2.1

[1]Means in each column followed by the same letter did not differ significantly at P = 0.05.

When soil sample means were combined over the study sites, one-way analysis of variance showed that there were significant differences in pH, P, K, Mg, Fe, Mn and Al levels between Manistee and Mason sites (Table 6). The Manistee site with its lower pH (mean 5.4, minimum 4.7) had more exchangeable Al, Fe and Mn than did the Mason site with its higher pH (mean 5.6, minimum 5.0). The Mason site had higher amounts of P, K and Mg which probably caused the higher tree heights (Table 2) than did the Manistee site. More Fe and Al were found in the B horizons (where the ortstein layer was present) than in the Ap or E horizons at both study sites (Abebe 1988).

The incidence of Septoria canker increased with increasing soil depth (the depth to the cemented ortstein layer) and tree height. Cytospora canker and poplar and willow borer incidences, however, tended to decrease or not change with increasing soil depth and tree height (Abebe 1988).

Soil nutrients (data were combined over the two study sites) that showed significant differences in their means when grouped by pest ratings are presented Table 7. Cytospora canker incidence increased as Fe and Al levels increased and K level decreased. Septoria canker incidence, however, increased with increasing levels of P, K and Mg and as Fe and Al levels decreased, while poplar and willow borer damage increased with increasing P and K levels.

DISCUSSION

The trees at the Manistee site were shorter (Table 2) and had a higher mortality rate (60% compared to 23%) than the trees at Mason. Mortality of the trees at the Manistee site was not caused by Septoria canker or borer (Table 3) but was associated with a high incidence of Cytospora canker. Cytospora canker was first noticed in the Manistee plantation in August of 1983,so other factors in addition to Cytospora canker are responsible for the high death rate.

Cytospora chrysosperma normally attacks wounded plants or those predisposed by stress (Schoeneweiss 1981). The reduced tree height and the 44 percent mortality rate (1978-1984) before Cytospora canker became prevalent suggest that the trees (NE 47) at Manistee were under stress from the time of planting. However, the NE 47 at Mason were also severely attacked by Cytospora canker at least on the branches (Table 4). NE 47 appeared to be growing reasonably well at Mason until attacked by Septoria canker (Table 4). Attacks by other more virulent pests in combination with various soil factors may have predisposed the NE 47 at Mason to Cytospora canker or this clone may be particularly susceptible to this pathogen.

Table 6.--Comparison of soil nutrient means (kg/ha) between the study sites.

Nutrient	Mason Mean	Mason Std. Error	Manistee Mean	Manistee Std. Error	Comparison[1]
pH	5.6	0.1	5.4	0.1	*
N	1.5	0.1	1.7	0.2	ns
P	100.4	11.6	22.4	2.4	*
K	29.8	23.0	17.3	1.6	*
Ca	587.5	153.0	562.5	90.9	ns
Mg	108.7	8.8	61.1	6.2	*
Fe	33.8	4.0	389.1	101.6	*
Mn	3.6	0.4	4.5	1.0	*
Al	72.7	6.6	125.5	24.6	*

[1]*=Means significantly different at P = 0.05, and
ns=Means not significantly different at P = 0.05.

Table 7.--Means of soil nutrients grouped by pest ratings.

Pest	Rating	P	K	Mg	Fe	Al
Poplar and	1	29.0a[1]	30.0a			
willow	2	101.4b	61.1ab			
borer	3	132.9b	65.5b			
Cytospora	1		63.5a		28.9a	22.5a
canker	2		31.2b		113.9ab	63.7ab
	3		25.2b		281.3b	134.9b
	4		33.6ab		448.4b	
Septoria	1	16.8a	26.9a	74.6a	218.4a	92.8a
canker	3	127.9b	66.1b	140.2b	37.6ab	22.6b
	4	80.7b	47.1b	239.3c	5.6b	26.3ab

[1]Means followed by the same letter within a column were not significantly different by Scheffe's procedure at P = 0.05.

Soluble Al in sufficient concentration is directly toxic to the roots of a wide range of woody plants. Al toxicity may be present in almost any inorganic soil with a pH less than 5.0-5.5, depending upon the sensitivity of the plant species (Foy 1974). The mean pH at Manistee was 5.4 (Table 6) with a low of 4.7. Steiner et al. 1984 reported the relatively high Al-sensitivity of some clones of hybrid poplars but NE 47 was not tested. Studies with birch seedlings revealed that N, K and P levels decreased gradually with increasing uptake of Al, while levels of Ca and Mg decreased rapidly thereby causing an Al-induced nutrient deficiency (Göransson and Eldhuset 1987).

The high levels of Al and Fe at the Manistee site (Table 6) may have been the cause of the stress which allowed Cytospora canker to devastate the plantation. In addition the soil at Manistee was deficient in K (Table 6). The occurrence of Cytospora canker has been associated with low levels of K in the soil in prune orchards in California (Bertrand et al. 1976).

Septoria canker incidence increased with increasing levels of P, K and Mg, and decreasing levels of Fe and Al (Table 7). It was also closely correlated with the amount of borer injury (Tables 3 & 4). The more favorable soil nutrient status of the Mason site apparently allowed the trees to reach the critical diameter for borer attack (Morris 1980, Moore et al. 1982). The insect wounds probably served as good infection points for S. musiva (Moore 1984). The weevil prefers trees with a smooth bark (Johnson and Lyon 1988). Septoria canker has also been reported to be more prevalent on clones (e.g. NE 308) which have smooth bark around the branches and bud scars (Woods 1985). Once the tree is wounded, S. musiva is a virulent enough pathogen to establish itself (Bier 1939).

In summary, the performance and productivity of a hybrid poplar plantation depends on the clones planted, site factors and the extent of pest damage. NE 47, which was planted at both study sites, grew faster at Mason than at Manistee indicating inherent differences(s) between the two sites. The Mason site had more P, K and Mg and less Fe and Al than the Manistee site. Thus, the Manistee site with its high water table, poorly drained soil, and high levels of Fe and Al was more stressful to the trees and hence Cytospora canker became common. A high level of Al in the soil may have been directly toxic to the roots or indirectly caused Al-induced deficiencies.

Conversely, the site-clone interaction at the Mason site were more conducive to faster tree growth. Unfortunately the smooth-bark clones planted at Mason were attacked by the borer and subsequently by Septoria canker. Hradel (1989) reported that NE 47, NE 235 and NE 308 were all severely attacked by Septoria canker in a Michigan nursery and suggested that their use be discontinued. Hence, these clones, perhaps irrespective of site, are not suitable for poplar plantations in Michigan.

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EFFECT OF GYPSY MOTH ON ASPEN IN MICHIGAN

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ABSTRACT.--In 1986 pilot studies were initiated to determine the effects of gypsy moth defoliation on bigtooth and quaking aspen in Michigan. Three 20-acre stands of mixed northern hardwoods were sprayed with Bacillus thuringiensis and three similar adjacent areas served as unsprayed controls. Results to date show that quaking aspen (average three-year defoliation was 35 percent) is preferred to bigtooth aspen (average three-year defoliation was 21 percent). Mortality of quaking aspen (8 percent/year) was four times higher than the mortality of bigtooth aspen (2 percent/year). Only trees with 80 percent or more defoliation in 1986 were killed by Armillaria root rot in 1987 or 1988. Do these results indicate that aspen with heavy defoliation are more susceptible to pathogens or that weak aspen are more likely to be defoliated by gypsy moth?

The gypsy moth (Lymantria dispar) is now well established in Michigan and defoliation by this insect may be devastating to the aspen resource. Previous work on non-clonal species (primarily the effect of gypsy moth as a stressing agent on oak in the Northeast) suggests this may be true. How a clonal woody plant (aspen) will respond to insect defoliation has rarely been studied in forest ecosystems.

Many types of stress increase the susceptibility of plants to disease. The best-investigated case of herbivore-pathogen interactions is the work of Wargo (1981a) and Houston (1981) who found that mortality results from a sequence of events that starts with gypsy moth defoliation, which predisposes oaks and maples to invasion by lethal secondary organisms. Wargo's (1981b) studies clearly show that secondary organisms (Armillaria mellea and Argilus bilineatus,) and not just starvation, are involved in the mortality of oak and maple after defoliation. Mortality of quaking aspen in Minnesota following defoliation by forest tent caterpillars was caused by the fungal pathogens Hypoxylon and Nectria and insect borers (Argilus) (Churchill et al. 1964).

The gypsy moth was first reported in Michigan in 1954. From 1954 to 1981 the gypsy moth defoliated (acreage with greater than 50 percent foliage loss due to gypsy moth) less than 20 acres per year. From 1984 to 1988 the totals were 7,000, 18,500, 64,000, 39,500 and 70,350 acres respectively. Thus the acreage harboring gypsy moth populations high enough to create defoliation has increased dramatically. Most of the counties with gypsy moth defoliation contain large acreages of aspen; both quaking and bigtooth aspen are preferred hosts of the gypsy moth (Leonard 1981, Herrick and Gansner 1987). In central Pennsylvania, aspen had a high mortality rate (8 percent annually) following gypsy moth defoliation, but represented less than 1 percent of the trees sampled (Herrick and Gansner 1987). How gypsy moth will impact the aspen stands of the Lake States in unknown.

Quaking aspen (Populus tremuloides Michx.) is the most widely distributed tree in North America. The range of bigtooth aspen (P. grandidentata Michx.) includes southeastern Canada and the northeastern United States. Aspens are a very important multiple-use species providing wood, water,

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forage, wildlife, and recreation. In Minnesota, Michigan, and Wisconsin aspen stands occupy more land than any other forest type (Jones and Markstrom 1973). Aspen represents 30 percent of the commercial forest area in Michigan and 30 percent of the harvest in 1979, far more than any other forest type (Jakes et al. 1982). Annual harvest of aspen in Michigan now equals or exceeds annual rates of growth, indicating that the aspen resource should be monitored to ensure that future shortages do not occur.

The objective of this study was to compare the reaction of two congeners (bigtooth and quaking aspen) to defoliation by gypsy moth and to determine the amount and cause of any subsequent mortality.

METHODS

The study was conducted in six areas, each about 20 acres, of mixed northern hardwoods in Midland County, Michigan. Approximately 5 percent of the forest canopy was comprised of aspen; oak of various species was common. No defoliation was detectable in 1984 during routine aerial surveys of the study areas. Similar surveys in 1985 detected significant defoliation (greater than 50 percent) within one mile of four of the areas and two were rated as having 75 percent defoliation.

Three areas were sprayed from the air in May of 1986, 1987 and 1988 with Bacillus thuringiensis. Three adjacent areas were not sprayed. No spraying was done in 1989. Spraying in 1986 was done from a Bell 47 helicopter fitted with 8004 Flat Fan Nozzles. Dipel 8L (16 BIU/A) in water was applied at a rate of 96 oz/A. In 1987 12 BIU/A of San 415 Bt in water plus 2 oz bond adjuvant at a rate of 96 oz/A was applied from an Ag Cat with 8006 Flat Fan Nozzles. In 1988 16 BIU/A of Dipel 82 Neat (undiluted) was applied from a Turbo Ag Cat fitted with Beecomist Rotary Atomizers.

During peak periods of defoliation (late June or early July) all aspen were examined within 25 subplots (10-factor basal area prism, one chain apart) in each area. Species, DBH, tree condition, percent defoliation (the percent of foliage stripped from each tree as estimated ocularly to the nearest 10 percent) were recorded for each tree. Data were collected on 75 bigtooth aspen with an average DBH in 1986 of 24.7 cm and on 113 quaking aspen with an average DBH of 23.9 cm. Trees which died during 1987 or 1988 were examined for the cause of death.

RESULTS

Sprayed plots had somewhat less defoliation than did unsprayed areas (Table 1). Defoliation was severe in 1986, decreased to very low levels in 1987, and then increased slightly in 1988 reaching moderate levels in 1989. In all years, whether sprayed or unsprayed, quaking aspen always had greater defoliation than did bigtooth aspen (Table 1).

In 1986 there were 25 quaking aspen with 70 percent or less defoliation; none died in 1987 or 1988. There were 88 trees with 80 percent or more defoliation in 1986; 8 died in both 1987 and 1988. Fifteen of the 16 mortalities were 100 percent defoliated in 1986. Seven trees had decay in 1986 and three of these died during the next two years. Of the 16 trees which died, five were listed in 1986 as sub-dominant, six as co-dominant, and five as dominant. The average DBH of the trees which died, 22.3 cm, was not significantly different from the average DBH for all trees, 23.9 cm.

Only three bigtooth aspen died during 1987 and 1988. One was a small suppressed tree in 1986 with 50 percent of its crown dead and 50 percent defoliated. The second also had a dead top in 1986 and 90 percent defoliation. The third was listed in good condition in 1986 with 100 percent defoliation.

Table 1.--Amount (percent) of defoliation of aspen in Michigan sprayed and not sprayed with Bacillus thuringiensis.

Year	Sprayed		Not Sprayed	
	Quaking	Bigtooth	Quaking	Bigtooth
1986	79	53	92	65
1987	5	2	4	0
1988	8	4	17	12
1989			44	19
Average	23	15	39	24

Armillaria sp. had colonized the roots or lower trunk of 17 of the 19 dead trees. Nine of the 17 had also been heavily attacked by Argilus and/or Saperda borers. No secondary organisms were observed on one of the dead trees and one had been extensively colonized by an unidentified Basidiomycete.

In summary, these preliminary results suggest that quaking aspen is preferred to bigtooth aspen by gypsy moth in Michigan. Average defoliation of quaking aspen was 35 percent; for bigtooth it was 21 percent. Mortality of quaking aspen (8 percent/year) was four times higher than the mortality of bigtooth aspen (2 percent/year). Death of most trees was associated with nearly complete defoliation in 1986 and the subsequent presence of Armillaria sp.

An important question that should be investigated is: Do these results indicate that aspen with heavy defoliation are more susceptible to secondary lethal organisms, or are weak aspen more likely to be defoliated by gypsy moth? The trees which died during 1987 or 1988 were much more likely to have had dead tops or decay in 1986 than trees which did not die. In some cases adjacent aspen had markedly different defoliation rates. For example, in one subplot there were four quaking aspen which had 10, 20, 20 and 80 percent defoliation in 1986. Only the stem with 80 percent defoliation died.

The only means of answering the above-posed question is to establish permanent plots in aspen stands prior to gypsy moth invasion. The vigor (e.g. growth rate, root starch levels) and condition of each stem would then be known when defoliation began. Only with this type of data will we be able to separate cause and effect.

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DEVELOPMENT AND APPLICATION OF A STATE-WIDE EMPIRICAL GROWTH AND YIELD MODEL FOR NATURAL ASPEN STANDS

David K. Walters and Alan R. Ek[1]

ABSTRACT.--Forest growth and yield modelling capability has progressed rapidly over the past few years, but few models are in regular use by practitioners. The STEMS model for the Lake States is one such tool with many possible uses. However, it requires tree list detail or the approximation of that to begin projections and, being a physically large package, it can require considerable effort to integrate this model into data base management systems. Simpler empirical yield models and PC-based implementation packages can enable many users to assess future forest resource conditions cost effectively now and at the same time facilitate eventual use of the STEMS model. This paper describes methodology and empirical equations developed for predicting basal area and multi-product yields by species for aspen stands in Minnesota. Independent variables are stand age and site quality, and, optionally, basal area. These equations facilitate rapid stand level projections. A computer implementation package is also being developed to assist forest managers and others in using these equations. Regeneration components and comparisons to existing models are also described.

INTRODUCTION

Empirical yield tables have been described in numerous forestry texts and articles (e.g., Husch et al. 1982, Bruce and Schumacher 1950, and Schumacher 1939). However, few empirical yield models exist except for those constructed from research data. Fewer still are used operationally in the Lake States region. Additionally, none we know of describe mixed species stand yields in detail. Several possible reasons for this void is that researchers have tended to ignore such approaches because they are too simple and management agencies have not had the technical support to develop them on their own (e.g., Ek (1987)). However, empirical yield models can provide an important tool for rapid yield projections with minimal software and hardware requirements. Previous work with an inventory data set in Wisconsin (Walters et al. 1989) also suggested that standard inventory data could be used to develop these empirical yield equations. Therefore, the methodology developed in these earlier studies was extended to the development of a statewide set of equations using USFS Forest Inventory and Analysis (FIA) data.

THE STUDY

A typical forest management operation in the Lake States might include ten to fifteen important forest cover types. This paper describes the development of a system of yield models for the aspen cover type in the state of Minnesota. The aspen cover type is described from 3487 FIA plots. These plots consist of 10-point clusters covering a 1 acre sample area. A 37.5 basal area factor prism plot is

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established at each point and three (3) 1/300 acre fixed radius plots are established on a subset of the points. The fixed radius plot is the basis for information on regeneration. For a detailed description of the plot establishment and measurement procedures, see Hahn and Hansen (1985). Stand-level volumes were computed from the individual tree information according to the procedure outlined by Hahn (1984). Each plot was randomly assigned to be used in either model fitting and development or in model validation. Statistical analysis of the data was conducted with the SYSTAT microcomputer package (Wilkinson 1988) and consisted of extensive correlation and graphical analysis and eventual linear and nonlinear regression model fitting. The data are described in Table 1.

The initial goal was to develop empirical yield model system for these data involving the following system of models.

$$B = f(A,S)$$

$$V = f(A,S,B)$$

where,

B = basal area of all species (ft^2/acre in trees => 1.0" DBH)
S = site index
A = stand age class
V = total stand volume of all species (ft^3/acre)

This system was designed to describe the yield over age relationships for various sites on an ownership. The first equation estimates basal area per acre for stands which are essentially undisturbed, that is with no history of thinning or other treatments. Such conditions are typical of aspen in the Lake States. The second expression estimates pulpwood volume as a function of site and age and the basal area from the first expression. Empirical yield equations typically describe stands of average basal area or stocking and the second expression does exactly that, except that the average stocking is represented by the first expression. Initially, models contained an intercept term because many stands still have some residual volume after clearcutting. Thus, even very young stands might have measurable merchantable volume. After initial screening of different models, the intercept term was found to be insignificant. Also, as aspen stands deteriorate at older ages, yields per acre can decrease. Again, the data often does not support models which allowed for this possibility.

Table 1.--Summary statistics for aspen data sets.

Variable	Minimum Value	Mean Value	Maximum Value
Model Fitting Data Set (1056 observations)			
Age	5.0	37.2	130.0
Site Index	36.0	66.0	99.0
Basal Area(ft^2)	1.2	74.7	212.2
Total Volume(ft^3)	0.0	1481.0	5550.3
Model Validation Data Set (2431 observations)			
Age	5.0	38.1	250.0
Site Index	20.0	66.7	99.0
Basal Area(ft^2)	0.6	75.6	212.7
Total Volume(ft^3)	0.0	1523.4	6747.3

Of the different model forms which were postulated and examined, the most promising basal area models were the following.

$$B = a_1 S^{a2} A^{a3} e^{a4/A} \qquad [1]$$

$$B = a_1 S^{a2} A^{a3} \qquad [2]$$

$$B = a_1 S^{a2} e^{a4/A} \qquad [3]$$

Similarly, several volume models were examined with three models being presented here which are quite similar to basal area equations [1], [2], and [3].

$$V = b_1 S^{b2} B^{b3} A^{b4} e^{b5/A} \qquad [4]$$

$$V = b_1 S^{b2} B^{b3} A^{b4} \qquad [5]$$

$$V = b_1 S^{b2} B^{b3} e^{b4/A} \qquad [6]$$

In addition to these three models, a segmented model was examined which effectively considers the yield (volume) relationship for stands less than or equal to 15 years old to be a linear function of age and the relationship for stands older than 15 years old to be adequately modeled by equation [5].

Thus, the model can be expressed as:

$$V = V_{<=15} + I(V_{>15} - V_{<=15}), \qquad [7]$$

where,

$$V_{>15} = b_1 S^{b2} B^{b3} A^{b4} \qquad [7a]$$

$$V_{<=15} = c_0 + c_1 A \qquad [7b]$$

$I=0$ for $A <= 15$ and $I=1$ for $A > 15$

and the model is conditioned such that

$$V_{<=15} = V_{>15} \text{ at } A = 15$$

This condition enables c_0 to be eliminated and [7b] to be re-expressed as

$$V_{<=15} = b_1 S^{b2} B^{b3} A^{b4} + c_1(A - 15) \qquad [7b]$$

A fourth equation for basal area growth (B) equation could be developed and applied if sufficient remeasured permanent plot data was available to construct it. The form of that model might be:

$$B = b_o S^{B2} (B^{b3} - b_4 B) \qquad [8]$$

Such data were not available in this case. The FIA permanent plots are currently being remeasured and when these additional data are available, the fitting of models such as [8] will be pursued.

Empirical yield models like [1]-[7] represent a smoothing of the average yields by age and site class represented in a compilation of an inventory. The assumptions in the fitting and use of such models are: 1) the plots have no history of management disturbance since the date of stand establishment and 2) the distribution of site quality for each age class is similar for all age classes. To the extent that the data included in the analysis meets the above stated assumptions, the equations estimate or approximate the natural development of stands. In effect, the average of stands now in a particular site class at age 40 provide an estimate of what the stands of that site class at age 30 will look like in another 10 years. In fact, such simple yield tables are very appropriate for many young stands prior to management treatments, say before age 20 in the Lake States region.

The inventory in this case contained other variables such as stand density and size class characterizations, but these were not deemed very useful in predicting future growth because of the likely change in density and size class with such aging. However, such variables are useful in an inventory context.

MODEL FITTING AND EVALUATION

Models [1]-[7] and other models were fitted to the data described in Table 1 using nonlinear least squares estimation procedures. To provide for an independent validation data set, each stand was randomly assigned to either a model fitting data set or a model validation data set. The model fit statistics used to evaluate the different levels of aggregation were mean residual, mean absolute residual, and mean squared residual in real (untransformed) units. Together, these three statistics and graphical inspection of residuals provided a good picture of the accuracy and precision of the models. The results for the basal area and pulpwood volume models are summarized in Table 2. After examining the results, model [2] and model [7] appeared to be the best predictors of basal area and total volume, respectively. In addition to the results in Table 2, residual and absolute residuals were compared across age classes. This comparison supported the selection of models [2] and [7]. The parameter estimates for these two models are presented in Table 3. Further analysis is continuing to examine the robustness of this selection for different cover types. Figure 1 presents projected total stand volumes using models

Table 2.--Comparison of basal area models [1], [2], and [3] and volume models [4], [5], [6], and [7].

Model Number	Statistics[1]			
	R^2	$\bar{D}$	$\lvert\bar{D}\rvert$	$(\bar{D^2})^{.5}$
[1]	0.867	0.463	23.749	30.02
[2]	.867	.376	23.723	30.00
[3]	.857	- .662	24.297	30.82
[4]	0.947	- 1.305	264.194	363.51
[5]	.945	-10.970	270.460	370.56
[6]	.937	-36.102	292.065	402.87
[7]	.947	0.230	262.440	360.55

[1]R^2 = coefficient of variation (percent of variation explained by model).

$\bar{D}$ = average difference between estimate and true value.

$\lvert\bar{D}\rvert$ = average absolute value difference between estimate and true value.

$(\bar{D^2})^{.5}$ = square root of the average squared difference between estimate and true value.

Table 3.--Parameter estimates for basal area model [2] and volume model [7].

	Parameter	Estimate
Model [2]		
	a_1	1.0810
	a_2	0.6277
	a_3	0.4577
Model [7]		
	b_1	0.1581
	b_2	0.8792
	b_3	0.8753
	b_4	0.4522
	c_1	-6.4618

[2] and [7]. One interesting point about these curves is that projected total stand volume does not decline at older ages. This is possibly due to the fact that gross (including cull) volume is currently being used as the dependent variable. It is expected that by subtracting the cull volume, the curve will peak and then begin to decline as rot and mortality become increasingly severe.

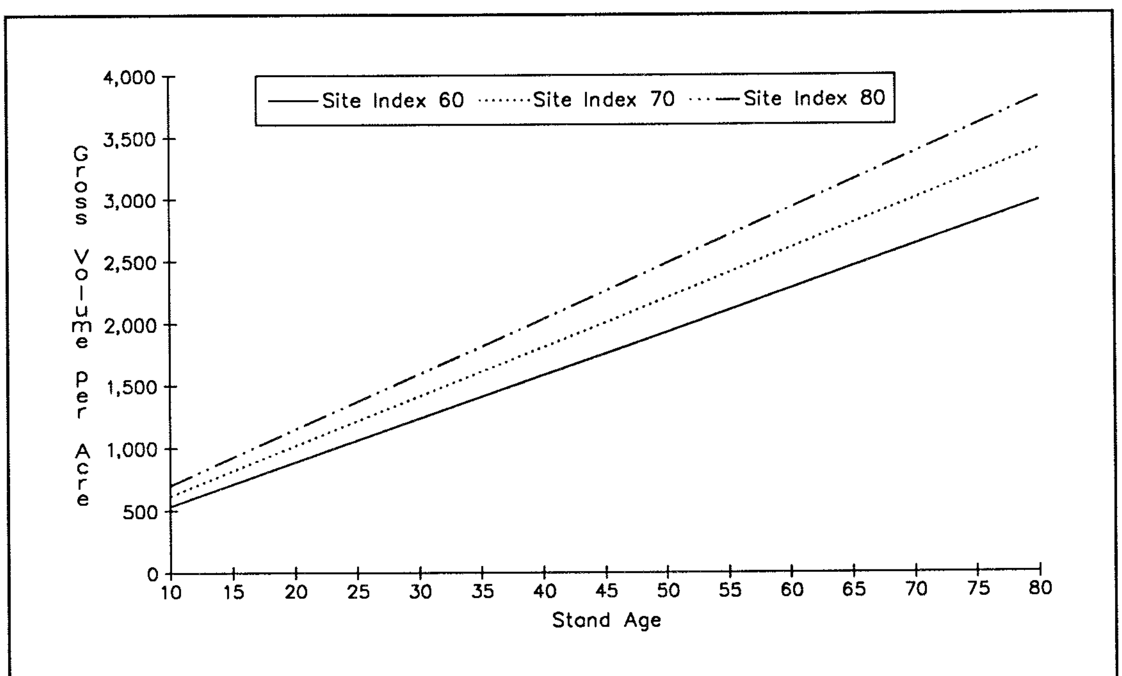

Figure 1.--Total cubic foot volume predicted for site indices 60, 70, and 80 using models [2] and [7] for basal area and volume projection, respectively.

IMPLEMENTATION AND FUTURE WORK

In practice, the basal area of stands following harvesting and lacking management disturbance is predicted with fitted model [2]. Note that this would estimate average basal area with respect to age and site quality. As many managers know, such averages may underestimate or overestimate basal area for some observed stands. That is expected. Where localized, stand yield information is available, predictions from, say age 20 to age 50, would be developed by forming a ratio of the predicted basal area relative to the known initial stand basal area. For example, a stand initially having 20 percent more basal area than the basal area model would be anticipated as having 20 percent more basal area than the model in the future. Total volume would be estimated using model [7] and the predicted basal area from fitted model [2] (after adjusting for any known initial basal areas). Alternatively, one could use known total volume to adjust the system following a similar algorithm as just described. However, there seems little basis for much deviation from the approach taken other than generalities about approaches to normality in the literature.

For handling mixed species stand conditions we would also proportion the yields such that stands initially noted to have 70 percent aspen, 20 percent softwoods and 10 percent other hardwoods would maintain these yield fractions in the future. After inspecting these data and the yield tables by Hahn and Raile (1982) that appears to be a tenable starting assumption. However, since the proportion of yields in various species groups may change as a function of basal area, age, number of stems, or other variables, the hypothesis that the proportion, P_{spp}, is a function rather than a constant is being tested. Work to date on this model indicates that there is little trend across site quality but that the number of trees per acre or quadratic mean diameter may be important indicator variables. If possible it would be desireable to avoid using either of these two variables because implicit in using them is the recognition that mortality or survival would have to be both estimated and projected.

Also important is the ability to break total stand volume into various merchantability classes. The approach being examined at the present is similar to that being proposed above to handle mixed species stand conditions. A proportion, P_{merch}, will be estimated as a function of basal area, age, number of stems per acre, top diameter, and other pertinent variables.

DISCUSSION

The approach to developing a stand level set of equations predicting basal area, total volume, merchantable volume, and volume by species groups is based on the assumption that what should drive such equations are variables which are readily available. Variables such as stand age, stand site index, and initial stand basal area are available in most inventory systems. Traditionally, these are the variables which were used to access tables of yield and basal area. By developing equations instead of tables, the results will be more conducive to application in inventory update programs and forest planning models. From a scientific viewpoint, such simple equations as we are proposing can provide reasonable starting points to examine questions about local differences in yield, and when these simple equations are made for several points in time, they provide a basis for addressing questions about changing climate and other global or regional concerns.

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AN ASPEN FOREST MANAGEMENT ADVISORY SYSTEM

H. M. Rauscher, D. A. Perala, and G. E. Host[1]

ABSTRACT.--An expert system program is described that advises the user on silvicultural treatments for aspen (Populus tremuloides Michx., P. grandidentata Michx.) stands of given age, site quality, and stocking. Growth models and stocking charts give tabular and graphical updates of projected stand development. Prescription recommendations enable land managers to make informed decisions on silvicultural treatments to obtain their timber, wildlife, and environmental amenity objectives. Hardware requirements: IBM PC AT/386 with hard disk, 640k RAM, and EGA or VGA graphics. Software requirement: MSDOS.

The link between research, professional field experience, and appropriate silvicultural practice in the aspen forest type (as in other types) is fragile and imperfect, but improving. The transfer of technology from the laboratory to the forest has evolved from fragmented and dispersed research notes and papers toward organized, integrated, user-oriented packages. In aspen management, the best example is the superbly detailed and illustrated state-of-knowledge book edited by DeByle and Winokur (1985). Summary handbooks (Brinkman and Roe 1975, Perala and Russell 1983, Shepperd and Engelby 1983, Perala 1986, Davidson et al. 1989), how-to guides (e.g., Steneker 1976, Perala 1977), and video slide tapes (e.g., Perala 1984, Shepperd 1986, Baughman 1988) have condensed the available research knowledge for everyday use. These technology transfer tools are effective but limited because they soon become dated and cannot interact with the user.

Rapidly emerging artificial intelligence technologies are being used to produce advisory systems to overcome these limitations of print technology. By simulating the decision-making logic of human experts, they can provide custom solutions to a large range of complex problems for anyone having access to a microcomputer. Furthermore, they can be updated relatively easily as innovations become available. Knowledge-based systems can integrate standard growth and yield models producing expert decision support systems. The essential improvement that advisory systems offer forest managers, scientists, and students is a way to apply the power of automation to the understanding, application, and management of forestry knowledge in support of teaching, research, and decision making.

Advisory systems must not be viewed as a panacea. They cannot be a substitute for good judgment. They cannot think but can manage the technical details and the large amount of available knowledge that burden even the most expert of land managers.

In this paper we describe an advisory system for the management of aspen in the upper Great Lakes region and highlight the critical data and rules that make it run. The system will be ready for distribution and validation in 1990.

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AN ILLUSTRATIVE SESSION

The Aspen Forest Management Advisory System (AS-FMAS) is made up of a number of modules (Fig. 1). A description of a typical cycle through the AS-FMAS will illustrate its use. First, the introductory screens identify the program and explain its purpose to the user. Then module #1 requests the user to enter standard stand description data (Fig. 2). The standard stand description data are asked for at the start of the session, rather than sequentially during the session, to increase operating efficiency. The user should enter as much of the requested information as is available - all, any part, or none. It is up to the advisory system then to analyze the user's input, module #2, and either estimate missing data or ask the user for additional information.

The user is asked next for the geographic location, used by the growth model, of the stand in question (Fig. 3). If the data analysis module requires no further user input to estimate missing data, the program continues to the stand condition analysis, module #3, which determines the health of the aspen stand. Module #3 has not yet been developed for the 1989 version of AS-FMAS, so no input is required. The management objective, module #4, asks the user to select the timber product objective

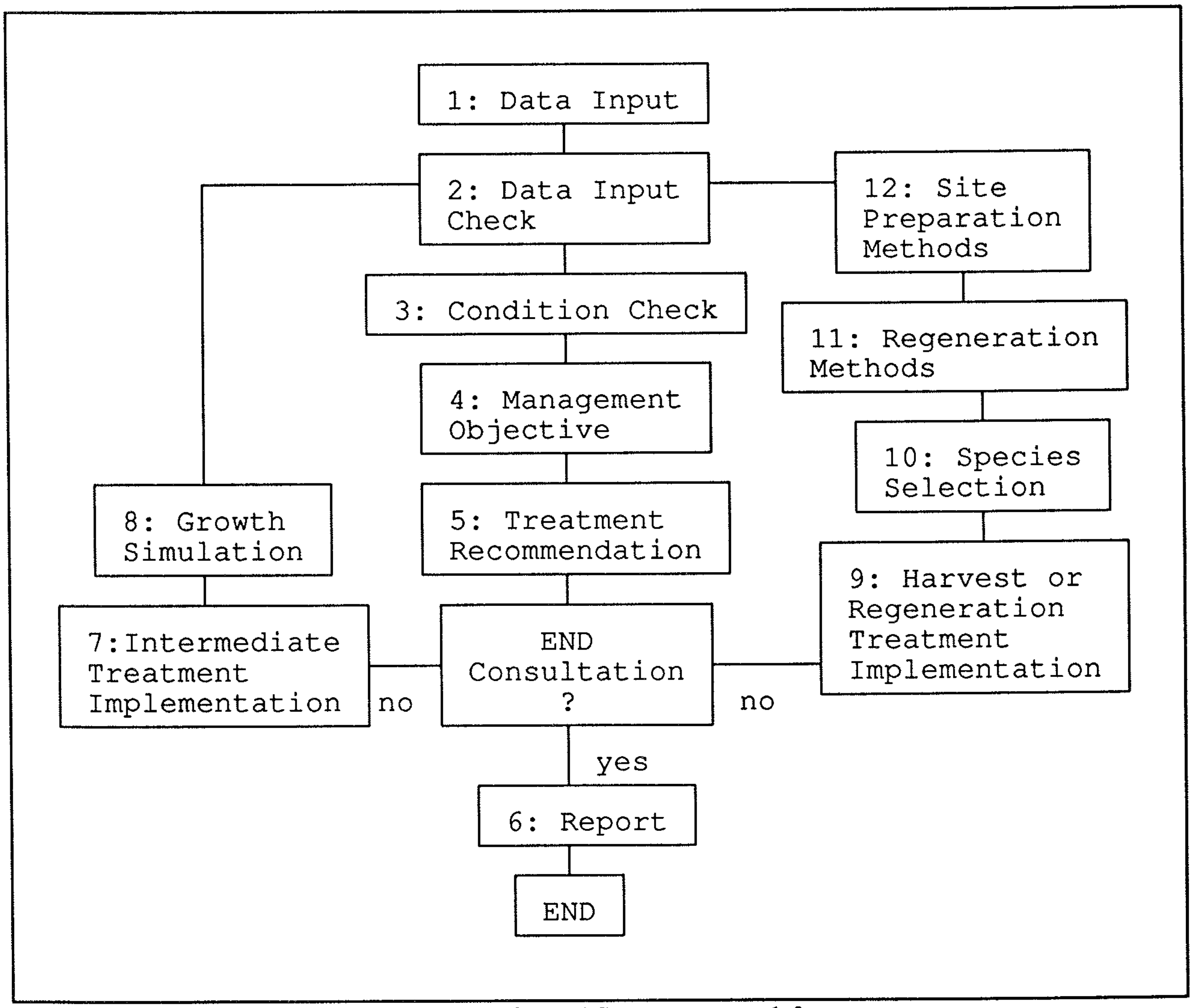

Figure 1.--Conceptual model diagram of AS-FMAS, an even-aged forest management system.

Please enter as much data as you can. Missing data will be estimated where possible by the expert system. You may be asked to provide estimates if the system cannot. The better the input the better the prescription recommendations.

		Value
AGE (yrs)	:	20
AVG. TREE DBH (in)	:	2.9
BASAL AREA (ft^2/ac)	:	70
TREES PER ACRE (#)	:	0
SITE INDEX (ft)	:	75
AREA (acres)	:	10
DOMINANT HEIGHT (ft)	:	0
VOLUME (cubic ft/ac)	:	0
VOLUME (cords/ac)	:	0
VOLUME (MBF/ac Scribner)	:	0

Figure 2.--Example of initial data entry screen in FMAS (module 1).

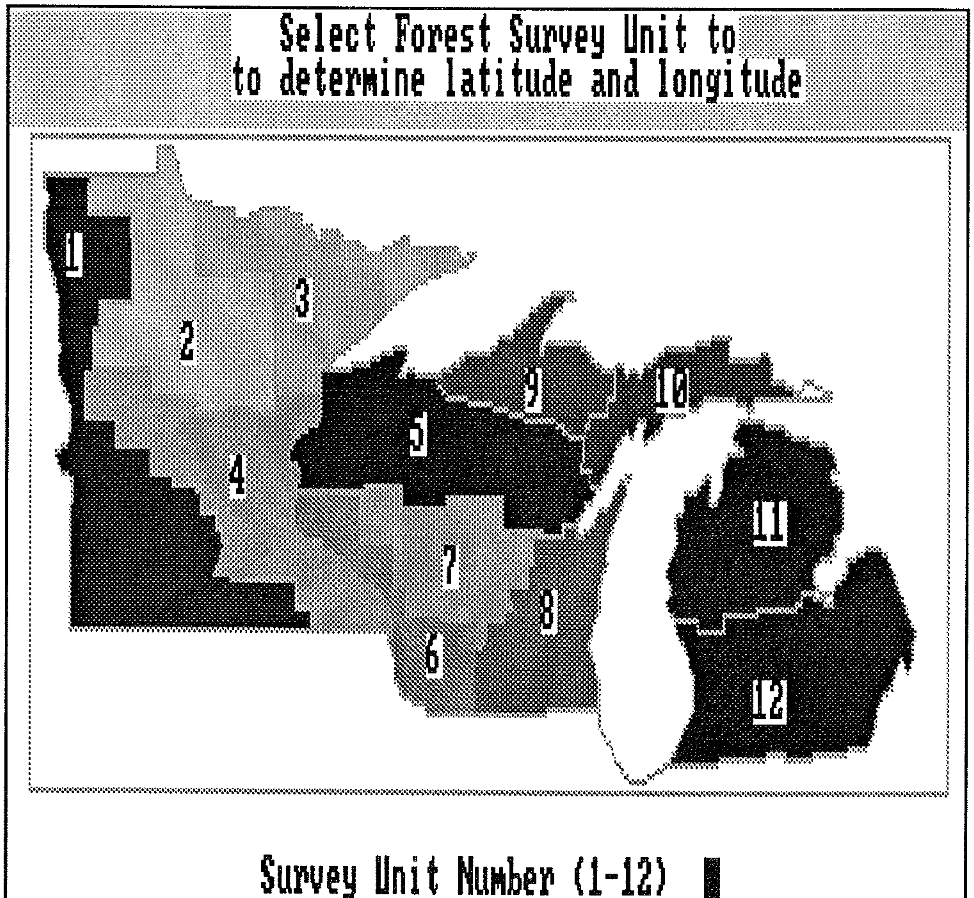

Figure 3.--Map to identify the geographic location of the stand.

for the stand; so the DBH goal for trees at the end of the rotation can be set and the rotation age can be estimated by the advisory system. The product objective is one of the key pieces of knowledge the advisory system needs from the user. The stand description (Fig. 4) then appears, displaying what is known about the stand at this point.

Continuing the program, the user is shown a list of treatment recommendations, module #5, and asked to select one for implementation (Fig. 5). Among the treatment options are conversion or regeneration without harvesting, release, thinning, harvesting, and postponing treatment. The advisory system presents only the treatment options logically possible for a given stand. An approximate "certainty factor", on a scale of 0-100, is reported next to each treatment which allows the user to make qualitative judgments on the advisability of selecting a given recommendation. The user is then shown the logic for recommending the treatment selected (Fig. 6). At this point the user may get a report of the results, module #6, and conclude the consultation.

```
Object Name:  Treatment Recommendation         ROTATION ENDS
THE STAND DESCRIPTION IS FOR YEAR: 2009        IN YEAR: 2015
Latitude: 47.0   Longitude: 94.8                 Recommended
                                             Minimum   Maximum
Covertype ....................: Aspen
Age (yrs) ....................: 40.0
Dbh (in) .....................: 6.1
Basal Area (sq.ft./ac) .......: 107       60        150
Trees per acre ...............: 534      295        738
Stocking density class .......: Within recommended levels
Site Index (ft) ..............: 75
Current Height (ft) ..........: 66
Acreage ......................: 10
                                            Specialty
Volume Cubft/ac ..............: 2313     Product Volume
Volume Cds/ac ................: 29         Cubft/ac ....: 0
Volume Mbf/ac (gross).Scribner.: 4.5     Biomass
Volume Mbf/ac (net)...Scribner.: 4.4       Tons/ac green: 99
                                           Tons/ac dry..: 51
Timber product objective ......: Pulpwood
Dbh goal at rotation (in) .....: 7
Rotation age (yrs) ...........: 46
```

Figure 4.--Example of the stand status report screen (module 5).

```
The following treatments and their associated confidence
levels have been recommended.  Please select one of these.
                      Recommendations
Certainty factor
             100   Harvest the stand
              20   Postpone treatment
```

Figure 5.--An example of a list of treatment recommendations (module 5).

```
You have selected to:  postpone treatments at this time

We recommend this selection with a certainty factor of: 20

BECAUSE :  Other treatments are recommended with a
           certainty factor of 100, normally one of
           those should have been selected.
```

Figure 6.--An example of a recommendation screen in AS-FMAS (Module 5).

If the user wishes to obtain future recommended treatments for the stand, the consultation may be continued. To illustrate, let us elect to 'Postpone treatment' for this stand. The cycle will go through module #7 where intermediate stand treatment implementation takes no action. Growth simulation, module #8, then asks the user to choose the conditions for stopping the growth and yield program. The user might choose to let the current stand grow until the next thinning is needed, in which case, the advisory system suggests a threshold basal area to trigger the next thinning. This value may be changed by the user if desired. Other choices available for stopping growth, include at a specified rotation age, when mean annual increment culminates, at a specified DBH, or after a specified number of years. Let us choose to grow this stand for another 10 years.

The growth and yield program is then activated to simulate growing the stand for 10 years. Expert systems are essentially static. For simulating changes over time, standard growth and yield models must be used. The result is a hybrid decision support system - part expert system and part simulation model. We developed our aspen growth and yield model specifically for this project; it illustrates the linkage between a conventional simulation model and an expert system. Such linkages are important in creating more useful expert systems in forestry. A stand table (Fig. 7) and a stocking chart (Fig. 8) are among the output screens available to the user upon request.

S T A N D   T A B L E

The expected rotation age is 45 years.
Site Index is 75 feet.

Year	Age	Ht	# of Trees	Dbh	BA	Pulp Cu Ft	Pulp Cords	Sawtimber Gross Mbf	Sawtimber Net Mbf	Sawtimber Resid. Cords
2009	40	66	534	6.1	107	2343	30	4.5	4.4	22
2019	50	75	349	7.8	115	3108	39	10.1	9.4	18

Figure 7.--Example stand table output from the growth and yield program.

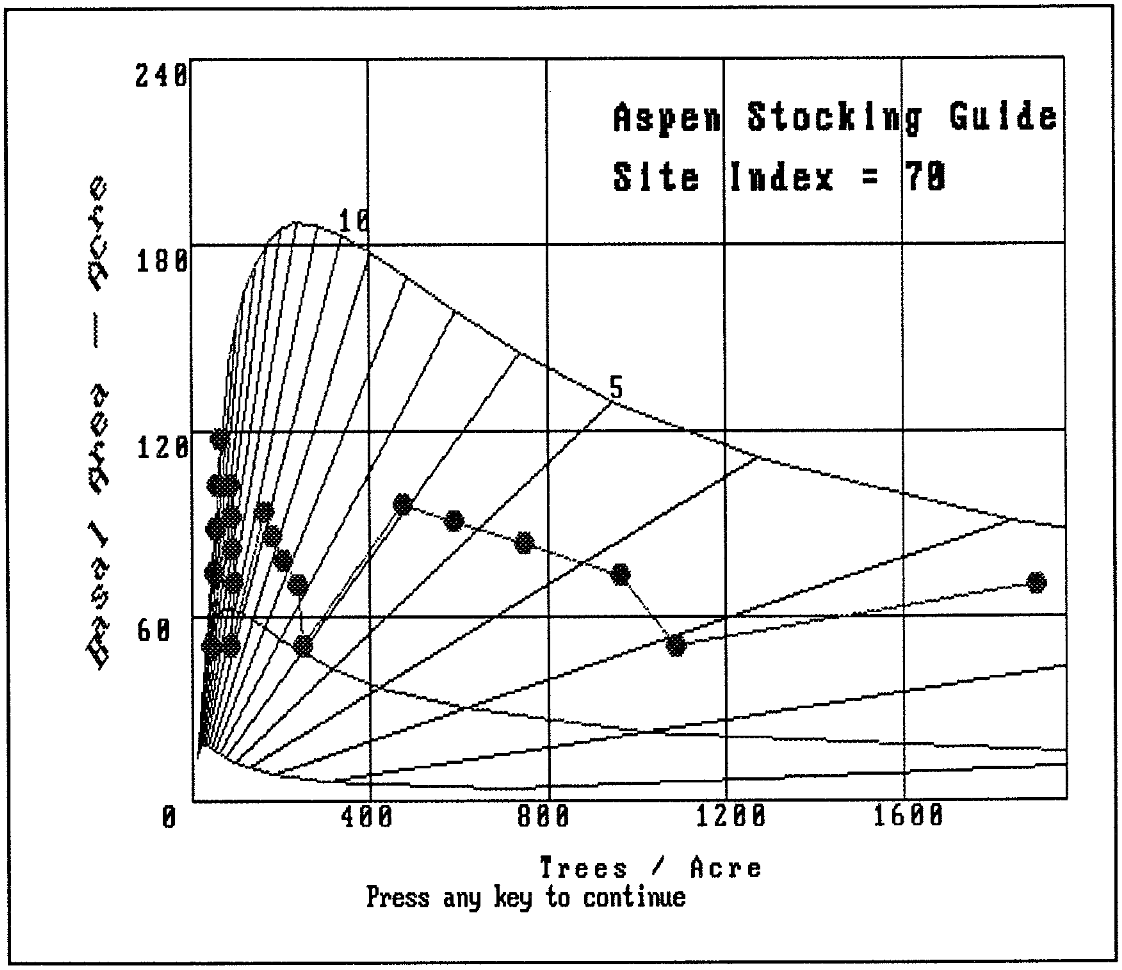

Figure 8.--Stocking guide for aspen.

The advisory system then cycles through selected intermediate stand treatments, under the control of the user, until harvesting is selected as a treatment recommendation. The silvicultural system recommended is clearcut (currently the only option) and the harvesting method, module #9, asks the user to choose one of three options: full-tree, tree-length, or log-length. The species selection, module #10, inquires whether the former species will be used for the next rotation or whether a new covertype will be established. If a new covertype is desired, the advisory system offers the user a species list, ranked by relative preference, from which to select the species or species group to favor. This list is based upon drainage, soil texture, and soil nutrients. If the choice of species is other than aspen, the system advises the user that AS-FMAS does not have recommendations for that species.

When aspen is selected for the next stand, the user is advised by the regeneration method, module #11, that suckering is the only option currently recommended. The advisory system then asks the user to select the timber product objective for the next rotation. Finally, the system helps the user select a site preparation method, module #12, based on drainage, litter conditions, vegetative competition, and other factors. The new stand description is generated and the AS-FMAS cycles back to the data input analysis, module #2, as if the user had entered this young stand from the keyboard. Whenever a treatment recommendation is generated, the user can either terminate the consultation or continue through another cycle. Upon termination, a multi-page report tracing the knowledge used to support the diagnosis is presented to the user. This report is presented by a word processor that can be used to make changes or annotations into the trace file and saved for future reference.

DOCUMENTATION

The decision rules are those used by Perala (1977). The user provides as much data as possible to the program. Missing data is estimated by solving for the item in question after rearranging terms in the normal stand equation (Perala in prep.) as shown below:

$$QMD=7.042*10^{-7}*(Trees/RSD)^{-0.265}*Site^{.632}*Age^{.852}*.995^{Age}*Lon^{-1.18}*1.02^{Lon}*Lat^{5.78}*0.87^{Lat} \quad [1]$$

where QMD=quadratic mean DBH (inches), Trees=density (trees per acre), RSD=relative stocking (decimal), Site=site index (mean height dominants and codominants, feet at 50 years (Lundgren and Dolid 1970), Age=total stand age (years), Lon=longitude and Lat=latitude (degrees). Stand age can also be estimated from equations given by Lundgren and Dolid (1970) if site index and dominant height are given.

The following growth equations (Perala in prep.) project stands into the future:

$$QMD_f=0.191*QMD_o^{0.987}*RSD^{-1.14}*2.573^{RSD}*Age_o^{-1.066}*Age_f^{1.08}*Site^{0.15}*0.998^{Site}*Lat^{0.052}, \text{ and} \quad [2]$$

$$BA_f=9.54*10^{-6}*BA_o^{0.744}*RSD^{-0.922}*2.63^{RSD}*Age_o^{-1.35}*Age_f^{1.524} *Site^{0.624}*0.993^{Site}*Lon^{-0.103}*Lat^{3.08}*0.947^{Lat} \quad [3]$$

where BA=stand basal area (ft^2 per acre) and subscripts "o" and "f" indicate present and future values. These equations were derived by analyzing log-log models applied to published data and tabular values from throughout the native range of aspen. Therefore, regional adjustments are possible by inputting geographic coordinates. These equations are being used temporarily until better ones are developed. Non-linear analyses of models similar to those used by Smith and Brand (1988) will probably provide the final equations.

Stand cubic foot and cord volumes, and biomass, are estimated using Schlaegel's (1975) equations. But four problems had to be solved before these equations could be used. First, Schlaegel's merchantable volume estimates depend on top diameter outside bark (DOB) while industry standards specify inside bark (DIB). This was remedied by developing an equation relating DOB to DIB:

$$DOB=0.041+1.031*DIB, \quad [4]$$

from his data set on file at Grand Rapids. Second, Schlaegel's merchantable volume ratios (MVR) apply only to tree DBH larger than the specified top diameter. Therefore, a modified Weibull nonlinear model (Yang et al. 1978) was fit to the tabular values of Table 158, Brown and Gevorkiantz (1934), to enable us to predict tree distribution by DBH class (DCL) for stands of a given QMD:

$$CFD=1-\exp(-0.2741*QMD^{-4.543}*(DCL+1.006)^{4.89}) \quad [5]$$

where CFD=cumulative frequency distribution (decimal). The third difficulty was that Schlaegel's MVR's are calculated from separate equations for whole top diameters (2 to 7 inches). This did not allow the flexibility needed to calculate MVRs for fractional DOBs predicted from eq. 4. Therefore, an equation was developed from a log-log model fitted to Schlaegel's predicted MVRs,

$$MVR=1-(0.0325*DBH^{-1.5}-0.99*\ln DOB-1.54*DOB*1.22^{DBH}*4.54^{DOB}), \quad [6]$$

to enable calculation of MVR from any DBH/DOB combination.

Finally, Schlaegel requires quadratic mean height (QMH) for calculating stand volumes. Perala (in prep.) provides an equation

$$QMH=9.49*HD^{0.88}*QMD^{0.236}*BA^{-0.0687}*Site^{-0.577}*1.007^{Site} \qquad [7]$$

to estimate QMH from more easily gathered dominant height (HD) and other stand data.

Sawtimber volume (board feet, Scribner) is estimated from

$$Saw=0.157*BA7^{1.146}*HD^{0.85}*QMD7^{.995}, \qquad [8]$$

where BA7 and QMD7 are stand values derived from a stand table integrated from outputs of eq. 2, 3, and 5 for trees 7 inches d.b.h. and larger. A log-log model was fit to values in Table 157 from Brown and Gevorkiantz (1934). Because sawtimber volume depends so much on freedom from decay, both gross and net volumes are estimated. Net sawtimber volume is derived from gross volume and the equation

$$USR=1-\exp(-1*(1.207*Site^{-1.1014}*(Age+12.02))^{5.852}) \qquad [9]$$

where USR=usable sawtimber ratio. Table 3 of Zehngraff (1947) provided the data for this nonlinear Weibull model.

Ek and Brodie's equation (1975) is used to estimate the amount of sucker regeneration following harvest and additional site preparation as needed. So far, the growth models (eqs. 2, 3) are only suitable for growing pure (or nearly so) even-aged stands of aspen. One of the critical remaining questions concerns the growth and development of mixed aspen stands, particularly two-storied stands where aspen suckers are sub-dominant to a residual canopy. These situations arise either by default when unmerchantable trees are left after harvesting, or by design ("deferment cutting", see Smith et al. 1989) when selected trees are left for amenity or wildlife purposes. The individual tree growth and mortality equations used in STEMS (Buchman 1979, Buchman and Lentz 1984, Hahn and Leary 1979, Holdaway et al. 1979, Holdaway 1984) will be examined to develop growth models for multi-storied stands.

SUMMARY

From a scientific point of view, the most important contribution of this project was to develop a **knowledge-based model** for aspen management in the upper Great Lakes region. <u>What seemed to be a clear body of knowledge about aspen management was actually inadequately and incompletely defined and organized.</u> Forest management is so complex and unstructured a domain, that creating a conceptual paradigm of the process proved to be a valuable scientific enterprise. It forced critical thinking, helped us generate new hypotheses, and demanded a comprehensive, holistic point of view to organize, synthesize, and thereby, compact the available knowledge. This knowledge-based model also provides a framework into which new research results on aspen stands can be integrated.

From a managerial point of view, we have developed an initial prototype for aspen management. The next stage of development is to extend and enhance the knowledge-base and validate the system so that it can deliver reliable, high quality treatment recommendations. Forest managers should profit from an increased access to specialized aspen management expertise. Through a continual testing-and-use cycle we expect to move this system toward scientific and managerial maturity.

From an educational point of view, the initial prototype of AS-FMAS is ready for study and discussion leading to suggestions for improving the aspen forest management advisory system.

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DEVELOPMENT OF AN ASPEN SUCKER STAND FOLLOWING IRRIGATION AND FERTILIZATION

G.W. Wyckoff, D.W. Einspahr, and M.K. Benson[1]

ABSTRACT.--A 16-18 year-old aspen stand was harvested in 1969. Aerial biomass components were determined and soils evaluated. Treatments of fertilizer, irrigation, fertilizer + irrigation and control were applied over a seven year period following harvest. Stand measurements were taken periodically over 18 years. Fertilization produced growth increases of 45-55 percent. Height, diameter, and stems per acre were affected by treatments. Guidelines for fertilizer application were developed from leaf tissue analysis.

INTRODUCTION

Interest in the growth potential of aspen led to research focused on the production of maximum growth in natural and improved aspen. The objectives were to demonstrate the biological potential of aspen and aspen hybrids. The program had the goals of: (1) exploiting available genetically improved species of Populus, (2) developing rotation age and harvesting system information, (3) determining the biological feasibility of such forestry practices as fertilization, irrigation, and whole tree harvesting.

Silvicultural Trial V (ST V) imposed treatments on a developing Populus tremuloides sucker stand immediately after harvest. One of the objectives was to demonstrate the growth potential of native aspen stands, the results of which are reported here. Other objectives, not reported in this paper, were to examine the feasibility of short rotation intensive culture for fuel and fiber, and study the impact of whole tree harvesting on nutrient removal.

The subject stand arose from clear cutting a 16-18-year-old sucker stand in the fall of 1969. Yield data from the stand were obtained by whole-tree chipping all trees in the stand, weighing chipped material and roundwood, and determining moisture content. The approach was made possible through the willingness of Owens-Illinois, Inc. to provide the site and harvesting and transportation equipment. Because of the size of the test area, sufficient chips were available for a millrun evaluation of pulping. Additional information from the original stand was obtained from eight 2/25-acre randomly located plots measured prior to harvesting.

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EXPERIMENTAL AREA

The test area is located in northern Wisconsin on Owens-Illinois, Inc. (now Nekoosa Packaging, Inc.) land at a site known as the Willow Flowage (Section 8, T-37-N, R-5-E, Oneida County). The 9.8 acre site is best described as a slightly rolling upland loamy sand about 10 feet above the flowage high water mark.

Soil samples were taken at three locations on the test area; texture and nutrient status information are given in Table 1. The texture of the surface soil was a loamy sand; nutrient analyses indicated N, P, K levels were comparable to and Ca and Mg were lower than those found on good aspen sites[2] (Koerper and Richardson 1980).

PARENT STAND INFORMATION

The study aspen stand originated from a commercial clear-cut made 15-20 years earlier, about 1950. Ring counts of stump disks from 24 trees indicated most were between 15 and 17 years of age with only one tree at age 18. Based on the ring counts, the original stand was considered to be 18 years old, recognizing it was probably a conservative figure. The stand also had few residual stems from the 1950 harvest; most of these were birch, red maple, spruce, and balsam fir.

Additional stand data were acquired by taking eight 2/25 acre circular plots. One of those plots was cut and weighed. Eleven trees were selected as representative of the area and dissected to determine moisture content, percent bark, and specific gravity. The dissected trees had an average of 45.3 percent moisture, 17.0 percent stem bark, and an average green volume specific gravity of 0.37 for wood and 0.44 for stem bark. The information from this plot (124 trees) was used to compute a regression equation which predicted fresh weight from height and diameter measurements. The regression equation was in good agreement with Bella (1968) and was used with the data from all plots to provide an estimate of the wood on the area. Table 2 provides a description of stand composition and wood volume. The stand had an average density of 1700 stems /acre. Aspen accounted for 98 percent of the stems and 95.6 percent of the basal area. Ninety-five percent of the aspen was P. tremuloides and five percent was P. grandidentata.

Table 1.--ST V soil texture and nutrient analyses[1] in 1969.

Location	Sand %	Silt %	Clay %	N	P	K	Ca	Mg	pH
Rep A	93	4	3	373	133	98	333	93	4.4
Rep B	92	5	3	308	135	85	412	110	4.4
Rep C	90	6	4	448	158	93	333	93	4.6

[1]Nutrient levels are pounds/acre; available N,P, K, exchangeable Ca and Mg.

[2]Institute of Paper Science and Technology, Atlanta, Georgia 30318, unpublished data.

Volume estimates (wood plus bark) were made from the eight plots listed in Table 2. Results from another study indicated inclusion of branches would increase the volume by 11 percent. Site index (base age 30) for quaking aspen was determined to be 52 (Graham et al. 1963). Hypoxylon mammatum canker was found on 5.7 percent of the aspen stems.

YIELD

Cutting the parent stand began in mid-October 1969 and was completed by the third week of November. Institute of Paper Chemistry personnel felled and windrowed the trees, and Owens-Illinois personnel skidded, chipped, hauled, weighed, determined moisture content, and pulped the chips. Eight-foot bolts with a minimum top diameter of 2.5 inches were chipped at the mill; smaller material was chipped on site.

All yield data were based on fresh weight and moisture content data. Volume equivalents, using green volume density determinations made on whole tree aspen (wood and bark), averaged 24.0 lb/cubic foot. Ovendry material averaged 21.2 tons per acre with an estimated mean annual increment of 2355 pounds per acre. These results are in close agreement with those obtained from the 2/25 acre plot measurements summarized in Table 2.

Table 2.--ST V original stand composition.

Plot Number	Stems/ Acre	Basal Area/A (ft^2)	Percent of Total Basal Area: Aspen	Percent of Total Basal Area: Other Hdwds	Mean Total Ht (ft)	Mean DBH (in)	OD Wt/ Acre (M lb)	Cords/ Acre (79 ft^3)
1	975	68	100	--	31.8	3.2	32.8	17.3
2	2100	102	90.2	9.8	30.1	2.7	48.0	25.3
3	1450	82	100	--	32.3	3.0	39.4	20.8
4	2400	90	94.2	5.6	29.2	2.4	41.3	21.8
5	1140	68	90.8	9.2	30.0	2.6	30.1	15.9
6	2190	100	90.0	10.0	30.4	2.6	46.9	24.8
7	1810	66	100	--	27.7	2.4	30.1	15.9
8	1550	74	100	--	29.5	2.6	34.2	18.1
Av	1700	81	95.6	4.4	30.1	2.7	37.8	20.0
Est. MAI							2.1	1.11

TREATMENTS AND EXPERIMENTAL DESIGN

The area was divided into 12 plots 150 x 200 feet in size with 10-foot lanes between plots and a 20-foot border around the perimeter of the area. Root connections between plots were severed in 1970 and 1971 and maintained annually with a brush disk. An eight-foot deer enclosure was placed around the trial.

Cost restricted irrigation treatments to a single area so the trial was laid out in a three-replicate, randomized block, split-plot design. Treatments consisted of a control, fertilization at 1000 pounds/acre, irrigation, and fertilization plus irrigation. A balanced, custom-made fertilizer with 20 percent N, 5 percent P, 10 percent K, 20 percent Ca, and 4 percent Mg was applied between May 27 and June 3, 1970 and again in June, 1975. Half of the nitrogen was supplied as ammonium nitrate, and the other half as a slow-release urea form. The fertilizer used was selected on the basis of soil nutrient and texture information[3] and earlier greenhouse and nursery studies (Einspahr 1971).

Irrigation treatments used water pumped from the Willow Flowage using a 25 horsepower engine. Water was delivered to plots through aluminum pipe to 11 high volume (40 gallons per minute) nozzles mounted on 10-foot risers that were later increased to 20 feet. Water application was based on soil moisture measurements made using both Bouyoucos blocks and gravimetric determinations. Circular plots for measuring growth were randomly located, and increased in size over time from one mil acre to 1/50 acre. The nutrient status of the trees on the trial was monitored by making leaf collections from all treatments, one sample from each replication of each treatment. Samples were collected in late August for the years 1970 through 1978. Levels of N, P, K, Ca, and Mg were determined for each sample.

RESULTS

Table 3 summarizes the growth information obtained for an eighteen year period from 1970 through 1987. Growth was good the first three growing seasons (1970-1972) with a significant height growth response due to fertilizer treatments. Fertilization also resulted in a significant reduction in number of stems per acre. Irrigation treatments had an increased incidence of *Venturia tremulae*, a fungal disease causing growing tip dieback. The disease occurs under conditions of high humidity, and causes a reduction in height growth. It was this dieback that produced a lack of growth response to irrigation. The effects of that disease were still evident 18 years later; the irrigation treatment had the lowest average height.

At age four (1973) a major natural thinning began in the control and irrigation treatments; thinning in the fertilization treatments was present from the beginning. Similar thinning effects from fertilization have been reported by other workers (Safford and Czapowskyj, 1986). The natural thinning process continued in all treatments at age 5 (1974) and tended to equalize the number of trees per acre. However, there remained fewer trees per acre in the fertilizer and fertilizer + irrigation treatments, and average height and diameter were significantly different. A volume loss in both 1973 and 1974 was a direct result of the thinning process (Fig. 1).

The fertilized areas received a second application in 1975. Measurements taken the fall of 1976 indicated there was no significant difference in number of stems per acre by treatment, although there appeared to be some reduction due to the reapplication of fertilizer. Average height, average DBH, average diameter growth, and total volume were significantly influenced by treatments seven years (1976) after the start of the trial.

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[3]Institute of Paper Science and Technology, Atlanta, GA 30318, unpublished data.

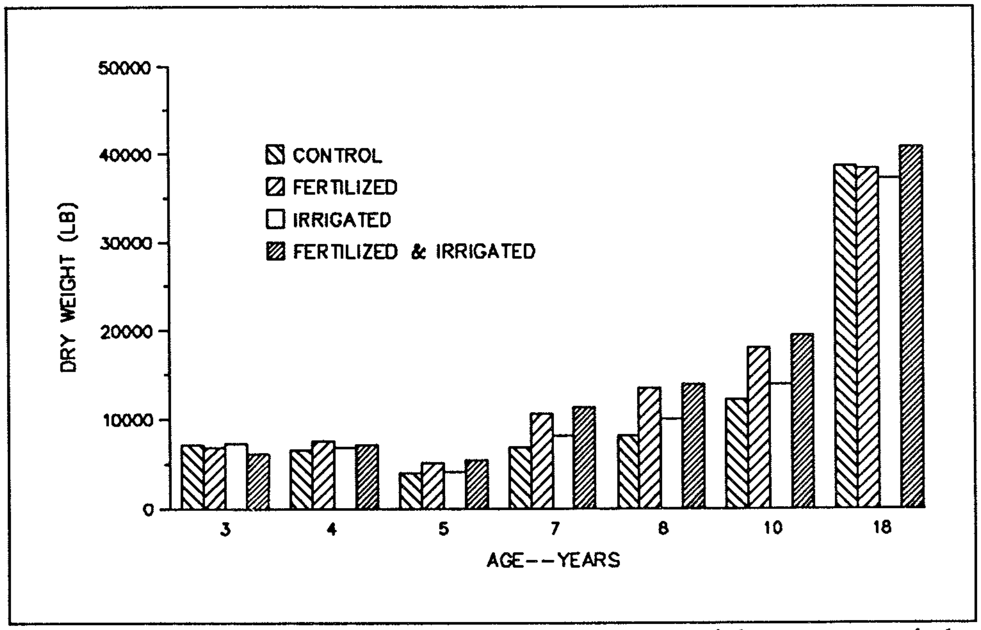

Figure 1.--Dry weight of stem wood produced over an eighteen year period.

Irrigation was discontinued after the 1976 growing season (year 7). The plots were remeasured in 1977 and 1979; at ten years, significantly greater volumes of wood were present on the fertilized (+47%) and the fertilized + irrigated (+55%) areas than on the untreated control areas. Wood volume on the irrigated areas was not significantly different from the control areas although the irrigation treatment supported a significantly greater number of stems than all other treatments.

Leaf nutrient measurements were made on trees from all plots through age nine (Table 4) to monitor soil nutrient uptake and to establish which elements were responsible for the growth increases obtained. Results from leaf analyses indicate nitrogen and, to a lesser extent potassium, are responsible for the growth increases. The data further indicates that response to nitrogen fertilization can be expected when leaf nitrogen levels drop below 2.8 percent and/or potassium levels drop below 0.9 percent, provided that other essential elements are at appropriate levels and soil moisture is not limiting. Based on leaf tissue measurements and upon growth rate comparisons during years 8, 9, and 10, there appeared to be no fertilizer carryover by age 10 on this sandy, well-drained site.

EIGHTEEN YEAR GROWTH

A growth response due to treatment was noted through age 10. The trial was measured at age 18 (1987) to see if those differences were still present. Table 3 summarizes the 18th year measurements. Diameter and stems per acre in the fertilizer treatments continued to be significantly different from the control and irrigation treatments ($p < 0.05$); stem diameters were greater and number of stems per acre were less. Total height and total wood volume were not significantly different.

DISCUSSION

Fertilization and irrigation of hardwoods is an interesting concept because of the high site requirements of hardwoods. Intensive management procedures like irrigation and fertilization may provide a better return on investment when applied to high value hardwoods like walnut and oak. Response of aspen sucker stands to fertilization is more difficult to interpret than evenly spaced hardwood plantations. Typically, irrigation produces height response and fertilization results in diameter growth increases.

Table 3.--ST V eighteen year growth.

Year	Height (ft)	DBH (in)	Aspen Stems/ Acre	Dry Wt. Wood (lb/acre)	Vol/A (ft^3)	Mean Annual Increment
CONTROL						
1970	2.8	--	33200	--	--	--
1971	4.3	--	27700	--	--	--
1972	5.7	0.5	22277	7224	315	105
1973	8.1	0.7	13523	6461	282	94
1974	12.0	0.8	5400	3891	170	57
1976	15.3	1.0	5188	6558	286	41
1977	16.1	1.2	4800	8107	354	44
1979	20.6	1.5	3266	12043	526	53
1987	36.1	3.0	1670	38124	1665	92
FERTILIZED						
1970	3.3	--	22300	--	--	--
1971	5.3	--	18300	--	--	--
1972	7.2	0.6	14814	6637	290	97
1973	9.6	0.8	10830	7549	330	83
1974	12.7	0.9	6222	5077	222	44
1976	17.3	1.2	5540	10403	454	65
1977	18.5	1.3	5115	13302	581	73
1979	22.6	1.8	3422	17717	773	77
1987	36.9	3.2	1425	37861	1653	92
IRRIGATED						
1970	2.7	--	38700	--	--	--
1971	4.2	--	30500	--	--	--
1972	5.3	0.5	24635	7257	317	106
1973	7.8	0.6	14926	6642	290	73
1974	11.9	0.8	5944	4134	180	36
1976	16.3	1.0	5811	8083	353	50
1977	17.3	1.2	5422	9867	431	54
1979	21.0	1.5	3755	13838	604	60
1987	34.7	2.9	1800	36771	1606	89
IRRIGATED & FERTILIZED						
1970	3.3	--	22800	--	--	--
1971	4.8	--	18900	--	--	--
1972	7.0	0.7	13883	5938	259	86
1973	8.8	0.8	11346	6767	295	74
1974	12.4	0.9	6209	5309	232	46
1976	17.7	1.2	5143	11111	484	69
1977	19.8	1.5	4300	13826	603	75
1979	24.0	1.9	3077	19090	833	83
1987	37.9	3.4	1320	40359	1762	98

Table 4.--Leaf nutrient levels.

YEAR	N	P	K	Ca	Mg
CONTROL					
1970	2.69	0.24	0.63	1.52	0.35
1971	2.43	0.18	0.71	1.02	0.24
1972	2.64	0.19	0.64	1.40	0.22
1973	2.83	0.23	0.86	1.38	0.33
1974	2.58	0.20	0.79	1.23	0.23
1975	2.40	0.17	0.74	1.03	0.22
1976	2.62	0.19	0.83	0.88	0.26
1977	2.71	0.25	0.90	1.43	0.32
1978	2.64	0.21	0.66	1.33	0.30
FERTILIZED					
1970	3.07[1]	0.24	0.83	1.23	0.33
1971	2.86[1]	0.20	0.98[1]	1.02	0.19
1972	2.84	0,19	0.80[1]	1.23	0.16
1973	2.81	0.23	1.06	1.44	0.28
1974	2.49	0.19	0.91	1.16	0.20
1975	2.82[1]	0.19	1.01	1.10	0.19
1976	3.16[1]	0.20	1.20[1]	0.77	0.20
1977	2.93	0.24	0.97	1.33	0.27
1978	2.64	0.21	0.80	1.40	0.21
IRRIGATED					
1970	2.76	0.23	0.87	1.52	0.30
1971	2.44	0.18	0.82	1.19	0.22
1972	2.59	0.19	0.74	1.24	0.21
1973	2.85	0.21	0.90	1.53	0.30
1974	2.51	0.17	0.90	1.21	0.19
1975	2.26	0.19	0.73	1.08	0.21
1976	2.64	0.20	0.93	1.23[1]	0.28
1977	2.78	0.23	0.85	1.53	0.35
1978	2.65	0.20	0.64	1.70	0.30
IRRIGATED & FERTILIZED					
1970	3.02[1]	0.23	0.83	1.41	0.27
1971	2.91[1]	0.21	1.03[1]	1.21	0.21
1972	2.98	0.19	0.82[1]	1.06	0.21
1973	2.75	0.19	1.00	1.46	0.29
1974	2.56	0.20	0.99	1.07	0.22
1975	2.87[1]	0.19	0.96	1.04	0.21
1976	3.16[1]	0.21	1.23[1]	0.89	0.23
1977	3.10	0.27	1.05	1.47	0.30
1978	2.60	0.20	0.79	1.40	0.19

[1]Values are significantly different from control ($p<0.05$).

However, competition between stems for moisture and light in sucker stands causes natural thinning and complicates the interpretation of results. In this study, fertilization resulted in improved diameter growth, increased competition between stems, and reduced the number of stems per acre. Irrigation through age seven failed to significantly increase average height after year ten except when combined with fertilization, apparently due to repeated tip dieback caused by the humidity-related disease Venturia tremulae.

The control plots had 33000 stems per acre at age one. Stem numbers decreased rapidly during growing seasons 2, 3, 4, and 5 with the greatest decreases during years 4 and 5 (-8700 and -8100 stems/acre). At age 18, the control areas had 1670 stems per acre which was comparable to the 1700 stems/ acre present when the stand was cut in 1969. Dry weight of wood (bolewood excluding bark and branches to 1/2 inch top) on control plots was estimated to be 38100 lb/acre and was comparable to the estimated 37800 lb/acre in the original stand. Growth for the 18 year period was 1.1 cords/ acre/year (79 ft^3).

The irrigation "only" plots had the greatest number of stems/acre (38700) at age one. Rapid thinning occurred, as with the control, during years 4 and 5. Stem losses were approximately 9300/year. Diameter growth was not improved with irrigation, and height growth was reduced by dieback from Venturia tremulae for the first four years. By age five, the trees had reached heights and stand densities where V. tremulae was not affecting growth. The irrigation "only" plots carried a larger number of stems/acre through the 18 year measurement period, although at the age 18 measurement, the number of stems and their diameter were not significantly different from the control.

Treatment response on the fertilized and the fertilized + irrigated areas was similar; there were equivalent numbers of stems at age one, natural thinning occurred at the same rate, and height growth was similar. Stems/acre at age one were about 22500 and thinning of 4-5000 stems/acre occurred through age 4. Fertilization treatments affected growth through age 10; at age 18, those differences were no longer detected and appear to be due to a lower number of stems/acre.

RECOMMENDATIONS

Silvicultural Trial V is located on an upland loamy sand site with a growing season water table at about 10 feet. Based upon observations of this site for 18 years, irrigation of aspen stands on similar sites is not recommended. Growth increases are low, application costs are high, and disease problems are increased.

Fertilization resulted in ten-year growth increases of 45-55 percent. Based upon leaf tissue analyses it is recommended that fertilizer include both nitrogen and potassium and that part of that nitrogen be a slow release form. An economic analysis undertaken at age 10 indicated that fertilization on upland sandy soils resulted in wood production increases about equivalent in value to application costs. Additional work should be considered to determine if an acceptable economic return may be obtained if higher quality sites are selected and fertilizer is applied 4-6 years prior to harvesting.

ACKNOWLEDGEMENTS

The authors thank Egon Humenberger and Bob Arvey for their assistance with field measurements. We are indebted to Bob Van Zandbergen and his staff at Nekoosa Packaging, Inc., Tomahawk, Wisconsin for their assistance in harvesting the test site and providing access to the test trial for these past 18 years. The information reported was accumulated while the authors were part of the Institute of Paper Chemistry (now Institute of Paper Science and Technology) staff. The financial support of the Institute and its aspen tree improvement cooperative is gratefully acknowledged.

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ASPEN THINNING AS A VIABLE CULTURAL TOOL

Brad S. Jones, William E. Berguson, John J. Vogel[1]

ABSTRACT.-- Implications of past results of aspen thinning research are discussed with reference to timber supply in Minnesota. Cost estimates of hand and mechanical strip thinning on an operational scale are compared. Current field experiments incorporating both hand and mechanical strip thinning are outlined along with plans for future research. Preliminary analyses indicate the potential to reduce aspen pulpwood rotations by ten years through thinning. Economic analyses show that an investment in aspen thinning could produce a positive return due to a reduction in rotation age and the capturing of increased value during a period of projected low supply.

INTRODUCTION

Minnesota forest inventory data indicates that the aspen resource in the state is imbalanced in age structure. Concern has been expressed over the effect of this age class imbalance on future timber supply. Using the 1979 inventory data, accounting for past harvest and regrowth, the current age class distribution can be estimated (Fig. 1). While this distribution varies by ownership, most projections show the same result; a lack of aspen acreage between the ages of twenty and forty. This indicates to many forest management agencies that the future availability and price of aspen is likely to fluctuate.

While traditional management practices will continue to be the bulk of the cultural work in the aspen type, alternative strategies are under development to address the anticipated reduction in aspen supply. Species substitution, development of genetically improved aspen, forest fertilization along with improved harvesting techniques are being explored as management strategies to help solve the problem in aspen age regulation. In addition to these techniques, the potential for precommercial thinning of aspen is being studied.

Many forest management agencies have used, and presently are using precommercial thinning in a variety of species to increase merchantable volume on specific stands. Also, in cases where an imbalance of age class exists over the forest as a whole, precommercial thinning is viewed as a tool to provide a more constant flow of timber over time. For example, paper companies in the northeastern United States are investing $100 to $200 per acre to thin natural spruce/fir regeneration to correct an age imbalance in the spruce/fir cover type (David Maass, personal communication). The intent of this management is to reduce rotations by 10 to 15 years to allow harvest during a period of projected low supply.

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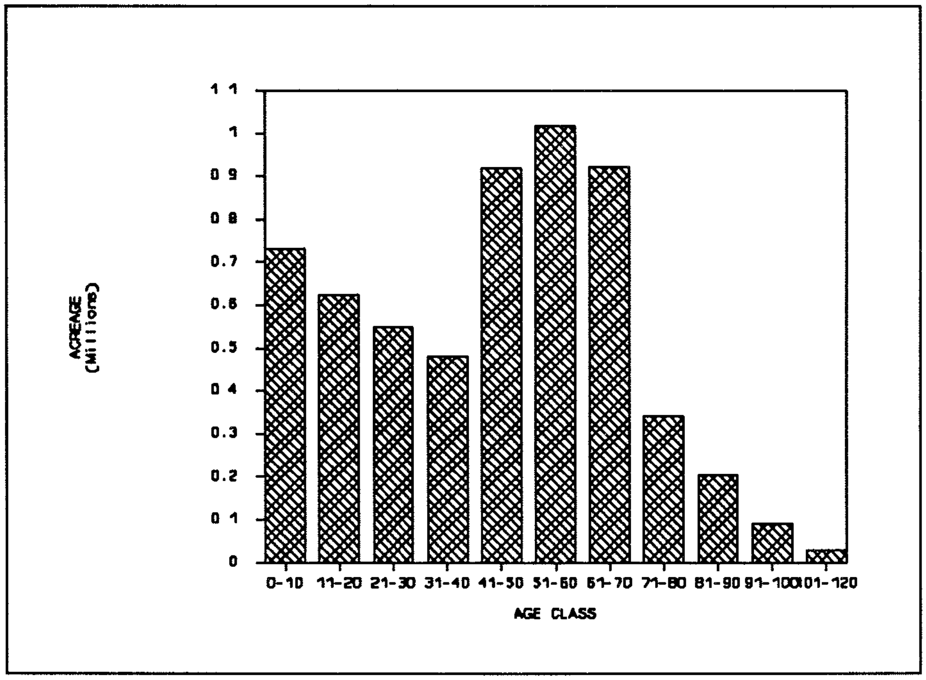

Figure 1.--Estimated 1987 age class distribution of the aspen cover type in Minnesota.

PAST RESEARCH

Aspen thinning research has been done using a variety of methods over a range of stand conditions. The primary goal of research was to develop methods to shorten rotations and increase quality for sawtimber. Studies done on very young stands, ages one to five, generally indicate a lack of response to thinning (Strothman and Heinselman 1957, Sorensen 1968). Also, thinning of stands greater than thirty years of age appears to be ineffective or only moderately effective. (Schlaegel and Ringold 1971; Hubbard 1972). However, the majority of thinning studies in sapling sized stands, ages seven to fifteen, indicate significant diameter responses (Day 1958, Schlaegel 1972, Steneker 1974, Bella 1975, Berguson and Perala 1988). Based on the results of these thinning studies, the purpose of research outlined in this paper is to determine the potential to develop cost-effective management strategies to thin sapling-sized aspen to accelerate diameter growth and shorten pulpwood rotations.

Results of hand thinning studies of sapling-sized stands reported by Berguson and Perala (1988), indicates the potential to reduce pulpwood rotations by ten years to age 30 through thinning. In these studies, mean diameters of thinned stands averaged one inch greater than the control stands at an average age of 18.5 years. Comparing results of these studies to published aspen yield tables (Perala 1977) for similar site indices, a ten-year reduction in rotation is estimated. Whether growth rates attained on hand thinning studies can be achieved through mechanical strip thinning is a subject of current research.

CURRENT RESEARCH

Two primary lines of investigation are currently underway. First, previously strip-thinned stands are being located and intensively sampled to determine the effects of thinning over time. Second, controlled experiments are being established on a variety of stands in cooperation with public and private land management agencies throughout the state.

MEASUREMENT OF EXISTING THINNED STANDS

In the late 1970s, large acreages of sapling-sized sucker stands were thinned by the US Forest Service. These stands are located in north central Minnesota on the Chippewa National Forest, a highly productive forest dominated by the aspen cover type. Stands ranged in age from seven to twelve years with both hand and mechanical strip thinning treatments done. These thinnings were operational in nature and not experiments, therefore, entire stands were treated. As a result, no control areas were incorporated within the stands and stand densities resulting from thinning are variable. However, these areas are a valuable resource from which to collect data as they represent 6 to 12 years of growth response to treatment.

Sampling is currently being done to verify control areas for comparison to thinned stands. Unthinned stands of same age, site index and soil type were located adjacent to, or in proximity to, thinned stands using USFS compartment exam information. Sampling is currently being done to verify that annual basal area growth during the years prior to thinning are identical in the thinned and unthinned stands. Only dominant trees are selected for comparison to minimize potential problems with the effect of inter-tree competition on growth of suppressed trees.

Once control plots are verified, permanent sampling points will be located in control stands and mechanically strip-thinned stands. Preliminary results of tree diameter data collected in 1988 in a stand strip-thinned at ten years of age shows that total stand basal area has recovered to equal that of the control stand in the nine foot leave strip treatment. Stand basal area is approximately 90 percent of unthinned stand basal area in the four foot leave strip treatment. Growth response of individual trees within these stands is shown in Figure 2. As control stands have not been verified at this time, results are viewed as preliminary.

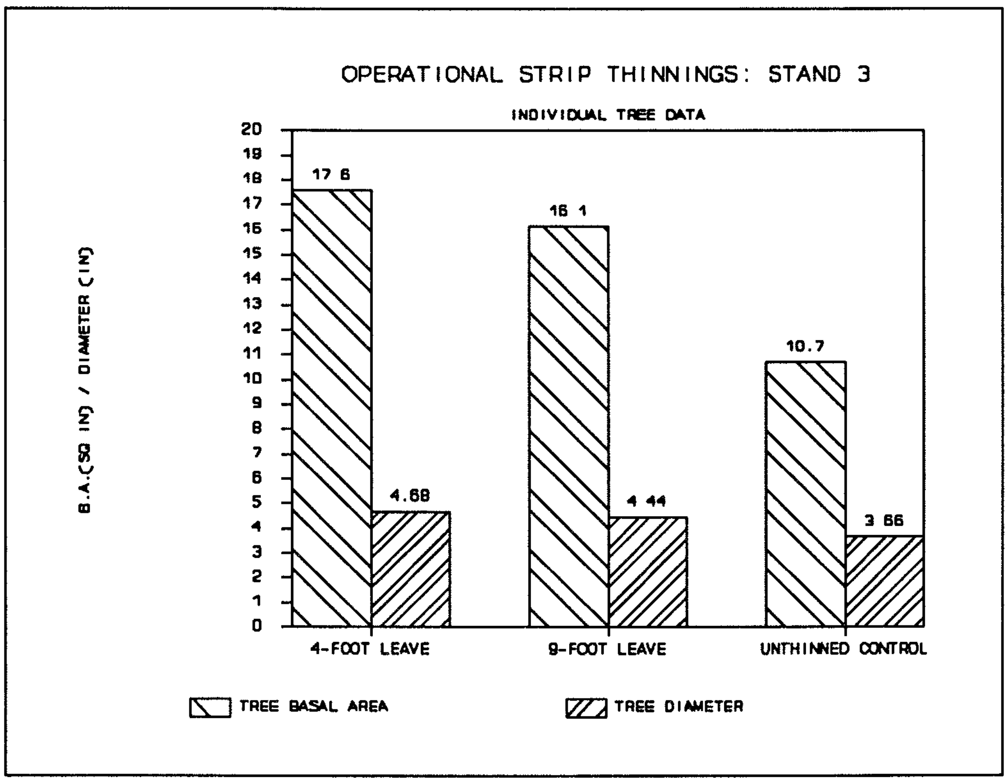

Figure 2.--Preliminary results of operational strip thinning studies ten years after thinning (700 dominant trees/acre).

THINNING EXPERIMENTS

Based on published results of hand thinning experiments and preliminary results of mechanical thinning, a series of cooperative studies were implemented by the Natural Resources Research Institute and land management agencies. These studies are designed to compare the cost-effectiveness of hand and mechanical thinning techniques on sapling-sized aspen stands over a variety of sites.
Hand treatments, done with sandviks or axes, are being considered to evaluate the potential to reduce down-time common with power equipment, to achieve consistent stand densities, and to provide optimum selection of crop trees. The size of material being removed (stem diameter less than 2") required little effort with hand tools. Two resulting densities were targeted using this method, 10 X 10 feet (400 stems/acre) and 8.5 X 8.5 feet (600 stems/acre).

Mechanical thinning is being evaluated in an attempt to develop a more cost-effective alternative to hand thinning. Treatments were prescribed using various types of equipment and the cost of each technique evaluated. The standard prescription was to shear eight foot strips alternating with an untreated strip. Leave-strip widths intended in these studies were four feet and eight feet. The resulting stand density should, therefore, be 1/3 and 1/2 of the initial density.

Also, a combined treatment was used which incorporated a mechanical thin to 1/2 the initial stand density (8 foot shear/8 foot leave strip) followed by further hand thinning in the residual strips.
This technique was used in an attempt to achieve consistent stand densities resulting from hand thinning yet reduce costs by using mechanical means to lower initial densities. The target density in this treatment is 600 stems per acre.

Data were collected during the establishment of thinning studies to determine the success in achieving prescribed densities. These data, shown in Table 1, illustrate the ability of operational treatments to attain target densities with a minimum of administration.

Many questions remain regarding the yield response of aspen to thinning, particularly mechanical strip thinning. Permanent plots established on these studies will help to better define the influence of stand density on the response of aspen to strip thinning. Since trees are not spaced uniformly after strip thinning, the increased growth of trees along a strip edge may induce higher mortality of suppressed trees in the interior of the strip. Stand densities at or near 700 trees/acre are intended for a pulpwood rotation. If growth increases occur primarily in dominants and codominants along strip edges, resulting

Table 1.--Comparison of prescribed and actual stem densities achieved in hand thinning studies.

	Prescribed Density	Actual Density
Control	---	7533
Mechanical		
4 foot leave	2500	2676
8 foot leave	3765	3749
Hand		
10 x 10 ft	400	417
8.5 x 8.5 ft	600	655
Combination	600	668

in the rapid mortality of suppressed trees in the interior of the strip, stands having a density greater than 2100 trees/acre may be treated. Data are currently being collected to quantify the distribution of volume within crown classes after thinning and the relationship of this growth allocation process to initial diameter distributions within the stand at the time of strip thinning. Along with this, tree mortality within the strip will be followed. Data will also be collected to assess the effects of thinning on basal area growth, height growth and branch:bole ratios.

ECONOMICS

During the establishment of field studies, cost data were collected accounting for all phases of the thinning operation. Costs per acre for each treatment are shown in Table 2.

Due primarily to the high fixed costs associated with traversing a site with a hand crew and the relative ease with which the trees could be hand thinned, no additional benefit was obtained from the combination treatment. As stem diameters are relatively small in this study (less than 2 inches), a combination treatment may be more applicable in a stand of higher average stem diameter.

To assess the economic feasibility of aspen thinning, a cash flow model was developed incorporating thinning cost data and current stumpage prices. Based on published results of hand thinning in Minnesota (Berguson and Perala 1988), it is assumed in these analyses that pulpwood rotations can be reduced by ten years to thirty years through thinning. It is also assumed that merchantable timber during a period of low supply (age 30) will be more valuable than stumpage ten years later. This is based on the fact that at age 40, larger volumes of timber will be available for harvest from regenerated unthinned acreage.

The stumpage price used in these analyses is $7.50 per cord for unthinned stands at age forty and $10.50 per cord for thinned stands at age thirty. The effect of no stumpage price difference between thinned and unthinned stands on the net present value was also calculated. Merchantable volumes on each stand were considered to be the same at the end of each rotation; thirty cords per acre. An administration charge of $5.00 per acre per year was applied to both stands. A real discount rate of four percent with no inflation and a cost of mechanical thinning of $25.00 per acre at age 15 were included in these analyses.

Using the assumptions outlined above, net present values per acre are $2.00 and $86.00 for the unthinned and thinned stands, respectively. The breakeven point is approximately $115.00 per acre for thinned stands. Assuming no stumpage price difference between unthinned and thinned stands, the net present value for unthinned and thinned stands is $2.00 and $38.00, respectively, with the value difference being due entirely to early availability of timber. These analyses indicate the potential to achieve positive economic returns from an investment in aspen thinning.

Table 2.--Cost ranges for aspen thinning treatments.

Treatment Method	Cost Range/Acre
Mechanical strip thinning	$12.00 to $25.00
Hand thinning	$50.00 to $65.00
Combination strip/hand thin	$75.00 to $90.00

CONCLUSION

While techniques to achieve optimally space stands are still being developed, it is apparent from existing data that thinning aspen stands results in shortened pulpwood rotations. Based on preliminary data, techniques exist which could potentially make thinning aspen a cost effective management tool. Further refinements of treatment type and recommendations for specific stand conditions will be made based on the results of field trials which are now in place. Indications are that aspen thinning may be an economically viable cultural management tool particularly on sites commanding higher stumpage prices, such as summer access sites. In order for aspen thinning to become an accepted silvicultural practice on forest lands in Minnesota, research underway on a variety of thinning methods must verify the biological and economic effectiveness of these treatments.

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COMMERCIAL-SCALE VEGETATIVE PROPAGATION OF ASPENS

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ABSTRACT.--The commercial potential for clonally propagated hybrid aspens (Populus alba x P. grandidentata) is substantial, but planting stock has not been readily available. We are testing techniques that include tissue culture and softwood cuttings to scale up new clones, plug culture for producing plug-1 stock, and the production of field stock by planting root cuttings directly in the nursery beds. Some of the roots of one year's nursery production are used in producing the next year's stock. Some refinements are still needed, but we believe the system provides the best potential for economically viable, large-scale production. The system should also work for improved clones of P. tremuloides.

INTRODUCTION

Starting in 1947, several naturally occurring hybrid aspen clones (Populus alba x P. grandidentata) have been discovered in southeastern Iowa (Little et al. 1957). Subsequent studies have shown the substantial growth potential of these hybrids. Annual height growth averaging 5.2 ft over the first 12 years and mean annual increments of 260 ft^3 have been documented (Hall et al. 1982). We have identified a number of potential uses for these hybrids, including sawlog production, energy plantations, Conservation Reserve plantings, stream and hillside buffer strips, and improving wildlife habitat (Hall et al. 1982, Schultz et al. 1989). We have begun breeding and selecting new clones of the hybrid for these uses (Hall 1989). More recently, we have begun working with P. tremuloides.

Unfortunately, the aspens are difficult to clone by using standard techniques; therefore, clonal stock has not been readily available for large-scale planting. Dormant stem cuttings typically root with less than 65 percent success (Snow 1938) unless substantial breeding and selection effort is focused on rooting.

Vegetative propagation by greenwood, or softwood "stem section" cuttings is possible with good success. Cuttings can be produced from stock plants grown in the greenhouse or from juvenile growth of field grown materials maintained as a cutting orchard (Faltonson et al. 1983, Faltonson 1983). The cuttings respond particularly well to the "quick-dip" method using 500-1000 ppm IBA (indolebutyric acid) solutions (Hartmann and Kester 1983). The best cuttings are obtained by beginning 6-8 inches

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back from the branch tip and cutting 4-5-inch lengths including two or more internodes. Cuttings may be obtained and rooted at any time of year using greenhouse-grown stock materials, but the best success for rooting (90-100%) is during the spring and early summer. After rooting under mist for approximately 3 weeks, the cuttings must be "weaned" for one week by reducing the mist interval or by placing the rooted cuttings in a shaded high humidity location. After this conditioning has been accomplished, it is also critical that the cuttings be removed from the mist without delay to avoid a decline in cutting vigor.

With close attention to scheduling, a propagator can produce several thousand softwood cuttings each season at a cost of approximately $0.50/tree. We routinely use this method to propagate trees for laboratory and field research. The technique also is a potential route for commercial production of planting stock. However, we believe that the root sprout system described in this paper is similar in cost and yields planting stock with better field survival and growth potential.

The aspens were the first type of tree to be successfully regenerated by tissue culture (Winton 1968), and the techniques have been substantially improved since then (e.g., Chun and Hall 1984). However, large-scale propagation by such means would require a significant effort by a tissue culture laboratory, rooting of the plantlets in a greenhouse, and transferring the plants to a nursery for growth to outplanting size. We estimate the cost of producing planting stock in this way to be at least $0.80/tree. The commercial production of aspen hybrids in Germany has been accomplished via tissue culture (Barocka et al. 1985), but we are unaware of any other large-scale applications of the technique.

Like other aspens, the P. alba x P. grandidentata hybrid is a successful root sprouter. Not only is this the preferred method of regeneration once new stands are established, but it also suggests a means for commercially propagating the initial planting stock (Starr 1971). Bailey's Nursery in St. Paul, MN, has propagated ornamental aspens by a means similar to the one tested and described in this paper. As far as we know, no name has been given to this type of planting stock. We propose the name "rootlings" to conform to terminology proposed for other types of clonal stock (Libby 1986).

MATERIALS AND METHODS

TISSUE CULTURE

Three clones of the P. alba x P. grandidentata hybrid, Crandon, Hansen, and Sherrill clones, were used in this study. Axillary buds were excised from actively growing shoots on greenhouse stock plants that were 4 months old. The buds were disinfested, then cultured on Gresshoff and Doy basal medium. Multiple shoots were then induced by subculturing the buds on media containing hormones (Chun and Hall 1984). After shoot initiation, 25 shoots from each clone were rooted in the greenhouse in Terra-lite® without hormone treatment. The plants were misted for 30 seconds every 5 minutes for 5 weeks. The rooted shoots were then hardened off and transferred to nursery beds in April, 1984. They were grown in the nursery beds for one year before lifting.

Another set of 350 Crandon tissue culture plantlets was started in 1988 by a similar method and then transferred to the nursery. Since then, we have begun evaluating an easier method for transferring tissue culture plants to the nursery. Multiple shoots are produced in tissue culture by using our standard techniques. They are then excised and placed in Techniculture® plug trays (stock number M40045, Castle and Cooke Techniculture, Salinas, CA) for rooting in a closed chamber. After 2 weeks of rooting, the trees are transferred to the greenhouse for 3 weeks of growth. To test this system, 20 plugs were transferred in August 1989 directly from the greenhouse to the nursery with no hardening-off period. The plants were approximately 2 inches tall at the time that they were planted at the nursery. These plants were well watered immediately after planting, and a shade screen was erected over the area. The nursery beds were periodically irrigated after planting.

NURSERY STOCK

In March 1985, the 75 clonal plants produced from our first tissue culture series were lifted from the nursery bed and top pruned to an 8-inch top. The roots on each of the plants were pruned back to a root ball of approximately 4 inches in radius (Fig. 1). Of the pruned roots, all roots smaller than 1/4-inch diameter were discarded. The length of the remaining material was measured and cut into 4-inch segments. The root segments from the three clones were then replanted in the nursery in separate beds. Planting was done by hand at a depth of 1 inch with the cuttings laid horizontally end-to-end. A 1-inch layer of mulch consisting of ground corncobs was applied to the surface of the beds. The beds were watered daily for the first 3 weeks, then as needed, depending on weather conditions during the rest of the growing season.

Each of the following springs, the rootlings were lifted. Using the same procedure as in 1985, the roots were pruned, and the excess root material was measured, cut, and replanted. Unfortunately, the beds were not mulched nor watered on schedule in 1987.

In 1989, an experiment was set up to more precisely test the size of root segment that would give optimal production of clonal plants. Roots were pruned from trees grown at both wide and normal spacings in the nursery. The roots were cut into four lengths: 1, 2, 4, and 8 inches, and then sorted into two diameter sizes: 1/4 to 1/2 inch and >1/2 inch. Replicate nursery beds of each type of planting material were established by using the planting depth, mulching, and watering procedures previously described.

The plants lifted in the spring of 1989 were also used to set up an experiment to evaluate methods for handling planting stock. A factorial design of two stem heights and two root-ball diameters was used. Tree stems were either left at their full one-year nursery height of approximately 32 inches, or they were cut back to half their height. The root balls were trimmed to either a 6- or 12-inch diameter. The trees were planted in a completely randomized row design with four replications.

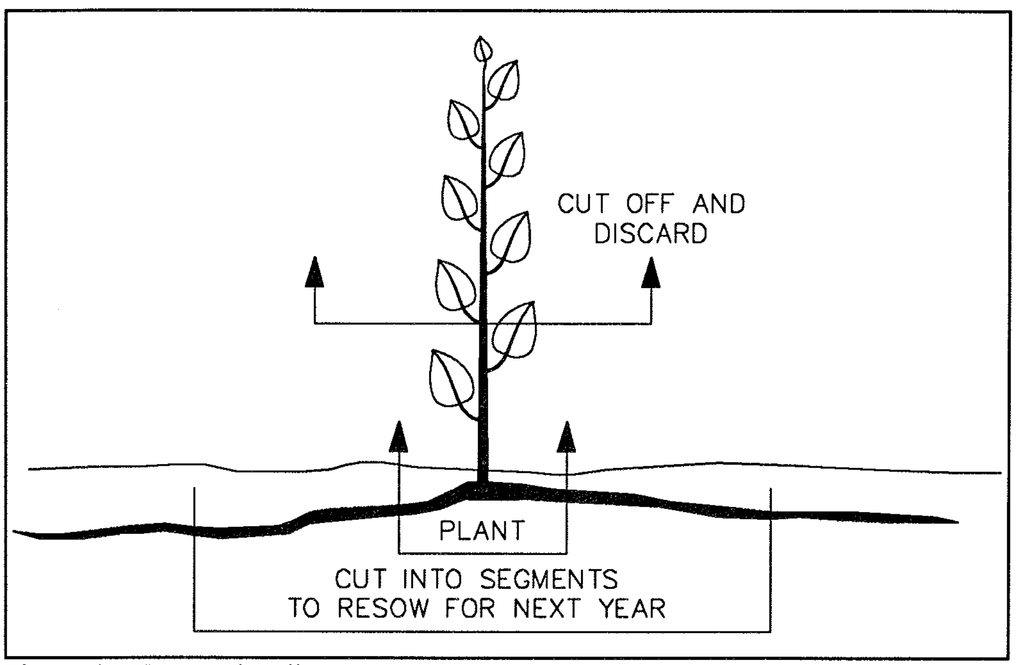

Figure 1.--How to handle nursery stock.

FIELD PLANTINGS

The 75 plants lifted in the spring of 1985 were hand-planted at the Rhodes Farm experimental area in central Iowa. The 1986 plants were shipped to Stephens State Forest in southern Iowa for use in machine planting of a wildlife habitat improvement plantation. The 1987 plants were auger-planted as a part of a species suitability trial on Conservation Reserve Program (CRP) land in southern Iowa. As explained later, there were no trees produced for planting in 1988. The 1989 plants were machine-planted in a demonstration energy farm at Hickory Grove Park in central Iowa.

DEVELOPING COST DATA

Production costs were estimated for micropropagated plantlets, rooted cuttings, and root segments (replants) based on work by Kolison (1986) and adjusted to 1989 costs by an inflation factor of 5 percent per annum. For each end product Kolison considered, the major production factors were identified from industrial and research sources. The input factors considered for the rooted and unrooted hardwood cuttings were land, site preparation, planting stock, planting, harvesting, and administration. For the micropropagation system, the factors were labor, laboratory, and greenhouse facilities, equipment, and supplies. New capital investments for the systems also were considered.

There are no known data on the production costs of producing aspen root segments severed from rootlings and for resowing them into nursery beds. It was assumed that the unrooted hardwood-cutting component costs for cottonwoods provide an initial point for estimation of costs for this new production system. We estimated that the costs involved in producing 4-inch root segments are double those of producing hardwood cuttings given the expected processing steps for lifting, cutting to length, sorting/grading, storage, and handling before replanting in the nursery beds.

Capital costs associated with producing plantlets by the micropropagation method were assumed to be $50,000 for all new facilities, equipment and supplies required to produce 3,333 hardened seedlings as input into the nursery phase of the aspen seedling production system. If existing greenhouse and laboratory facilities can be used or adapted with minimal costs, the capital costs are estimated to be $15,500, for specialized equipment and supplies for tissue culture. All capital cost estimates are based on Kolison (1986) and have been inflated to 1989 costs at 5 percent per annum. The costs represent the minimum facilities needed to produce 3,333 tissue culture plantlets. We assumed that nursery facilities were already owned, and we included land rent in the production cost estimates for the rootlings (Kolison 1986).

RESULTS AND DISCUSSION

TISSUE CULTURE

One hundred percent of the original tissue culture plantlets survived after transplanting to the nursery. Survival of the 1988 set of tissue culture plants was more than 95 percent. In our very small 1989 experiment in moving plug-reared plants to the nursery in August, we achieved 85 percent survival. Survival rates consistently above 90 percent for tissue culture plantlets transferred to the nursery in the spring should be realistic.

NURSERY STOCK

There was sufficient root production from the original 25 tissue culture trees of each clone to increase overall stock levels in the next season (Table 1). There was an increase factor of 2.28 to 5.92 in the three different clones in the first year. The Sherrill clone had very poor production from 1985 to 1986,

Table 1.--Rate of increase in nursery stock production in 1986.

	Clone		
	Crandon	Hansen	Sherrill
Number of trees produced in 1986 from 1985 roots	99	148	57
Rate of increase from 25 starting trees	3.96	5.92	2.28
Total length of excess root growth per tree in 1986:			
inches	18.6	22.0	23.5
number of 4" segments	4.6	5.5	5.9

producing only about 26 ft of plantable root segments from 57 stems. The other two sprout sources produced an average of 82 ft of plantable root segments. In the 1986 growing season enough excess root growth was produced to again give an average 144 percent increase in numbers of plantable rootlings (Table 1). This is a 400 percent increase in 2 years from the original nursery stock started by tissue culture. In 1987, each clone produced an average of 210 ft of plantable root segments, more than doubling the 1986 root production. From 1985 to 1987, new stems were being produced at a rate of 1 stem for every 10 inches of planted root; a 38 percent success rate for the 4-inch root segments that were being planted.

However, in 1987, mulching and daily watering did not occur for 2 weeks after the planting of the root segments because of an oversight in nursery practices. Unseasonably warm and dry conditions prevailed during this period. As a result, very few of the planted root segments sprouted. None of the Sherrill clone survived. Only a few Crandon sprouts were observed. About 10 sprouts of the Hansen clone were produced in midsummer of 1987. When a sample of the remaining Hansen root segments was examined, the segments were still alive, but apparently in a dormant state. Therefore, that bed was left intact for the 1988 nursery season. Another 35 Hansen plants sprouted from the root segments in the second growing season after planting the roots. Because of time constraints, we chose to reinitiate bulk production of only the Crandon clone by planting 350 tissue culture trees in the nursery in 1988.

The results of our 1989 nursery experiment on the effects of root segment size are summarized in Table 2. Root segments larger than 1/2-inch diameter do produce more root sprouts. In fact, for root segments 2 inches long and longer, these large-diameter roots frequently produce more than one sprout per segment. However, these segments with multiple sprouts would have to be given special handling to separate each sprout into a plantable unit. Furthermore, large-diameter roots are not produced in significant numbers when plants are grown at normal bed densities. We only had large roots available because of the wide spacing that occurred in the Hansen nursery bed that was planted in 1987 and held over with scattered sprouting in 1988. Therefore, we anticipate that commercial production of rootlings will depend mostly on planting 1/4- to 1/2-inch diameter root segments. Cutting these segments to 8 inches length gave the greatest percentage of segments that sprouted (Table 2), but 4-inch long segments gave maximum production of sprouts per total root length planted. In fact, 2-inch long segments are almost as good as 8-inch segments when considered on the basis of sprouts produced per total length of roots planted.

Table 2.--Number of trees produced/100 segments of root in 1989 nursery study. Combined results from Crandon and Hansen clone.

	Size of Root Segment (inches)	
Length	Diameter	
	1/4 to 1/2	>1/2
1	6	5
2	20	43
4	53	100
8	87	133

Another potential problem was identified in the 1989 experiment; many of the rootlings exhibited what appeared to be crown gall disease caused by Agrobacterium tumefasciens. Such infected stock must be discarded. To avoid similar problems in the future, nursery beds should be fumigated prior to planting the root segments.

FIELD PLANTINGS

Survival at the end of the first growing season in the field has been very good. Of the first 75 trees planted in 1985, 93 percent survived; five trees were killed by animal damage. The 1986 planting had an overall survival of only 83 percent, but more than 65 percent of the mortality occurred in three rows that seemed to have received excessive post-planting doses of linuron herbicide. The 1987 planting on a CRP site had over 93 percent first-year survival, but did lose many additional plants in the second and third year due to a severe drought.

A detailed analysis of survival and growth of the 1989 planting stock is presented in Table 3. All four approaches to preparing planting stock gave good survival. Plants with unpruned tops and the larger root ball were taller at the end of the first season. However, the differences in height do not seem to offset the ease of handling stock that is cut back to a shorter height and the value of the extra root material that can be trimmed and used for the next cycle of rootling production.

ESTIMATED COSTS OF PRODUCTION

We estimate the 1989 production cost range for rooted cuttings as \$0.32 - \$0.39 per plant. The cost range for the root segments to be replanted in the nursery is \$0.07 - \$0.09 apiece. Micropropagated, hardened plantlets cost between \$0.78 - \$0.88 each to produce assuming new laboratory and greenhouse facilities are needed for their production. If existing facilities can be used, then these costs can be reduced by as much as 29 percent.

Based on our experience, we believe that the following steps will work in bringing new aspen clones into full-scale commercial production (a numerical example is presented in Table 4 to illustrate the cost of the procedures):

1. Decide on the target level of cloned plants to be produced each year (e.g., 90,000 plants per clone per year).

Table 3.--First year results for the 1989 planting of aspen hybrid rootlings at Hickory Grove Park.

Treatment: Stem	Treatment: Roots	n	Survival (%)	Total Height (cm)
Cut to 1/2 height	Cut to 6" diameter ball	86	100	191
Cut to 1/2 height	Cut to 12" diameter ball	83	100	206
Left full height	Cut to 6" diameter ball	89	99	204
Left full height	Cut to 12" diameter ball	73	100	218

2. Decide how rapidly you want to reach full-scale production by balancing the factors of production against one another. Table 4 is based on a five-period program to bring a new clone on line. The first period is the *in vitro* micropropagation phase. The input is 333 meristematic tips from a small set of mother trees. We estimate that over a 19-week period, the initial number of "plantlets" will increase by a net factor of 10. Thus, the output is 3,333 hardened plantlets, which are planted in the nursery and become the inputs to the second period. The estimated total cost of production ranges from $1,833 to $2,933 depending on the capital costs that may range from $15,500 to $50,000. The second period is the first nursery-production phase of the system. The 3,333 hardened tissue culture trees from period 1 are the input.

3. Before the first and subsequent year's nursery production is lifted from the beds, it should be top pruned to a height that will simplify handling and machine planting (Fig. 1). We prefer to leave an 8 to 10-inch top.

4. Lift the clonal plants and trim the root ball back to a 6-inch diameter. This can be done during the grading process by gathering 5-10 trees into a bundle and using a machete or paper cutter to prune the roots.

5. Trim the roots into 4-inch lengths, discarding pieces that are less than 1/4-inch in diameter (Fig. 1). Store these segments under refrigeration until ready to replant the nursery beds. In our example (Table 4), the output from the first year of nursery production is approximately 20,000 root segments. About 50 percent of those segments can be expected to give rise to rootlings in the second year of nursery production.

6. Make four furrows about 1 inch deep in a well-tilled, fumigated nursery bed and hand-plant the root segments by laying them end to end in the furrows. Close the furrows and add sufficient mulch to ensure the root segments can not dry out between waterings.

7. Keep beds well watered until sprouts emerge, then water and fertilize as needed to promote good growth.

8. Annually repeat steps 3-7 for as long as the particular clone remains in demand for planting. In our example (Table 4), it takes 4 years of nursery production to reach full output. At that point, the unit cost of a plantable tree is $0.46-0.57. Considering the high survival rates of this type of planting stock, the genetic value of having clonal stock rather than seedlings, and the natural root sprout regeneration system that will carry a new planting on into future rotations, we believe that this is a competitive price for nursery stock compared with other species and other techniques for aspen.

Table 4.--Input, outputs and undiscounted costs of producing aspen clonal stock by a combined micropropagation, root segment (rs), and rootling (rt) production system.

	Input	Outputs	Unit Cost ($/item)	Total Costs
Micropropagation Phase				
New facilities				
Period 1	333	3333	$0.78 - $0.88	$2600-$2933
Existing facilities				
Period 1	333	3333	$0.55 - $0.69	$1833-$2300
Root Segment (rs) and Rootling (rt) Phase				
Period 2	3333	20000 rs	$0.07 - $0.09	$2800-$3600
		3333 rt	$0.32 - $0.39	$1067-$1300
Period 3	20000	60000 rs	$0.07 - $0.09	$8400-$10800
		10000 rt	$0.32 - $0.39	$3200-$3900
Period 4	60000	180000 rs	$0.07 - $0.09	$25200-$32400
		30000 rt	$0.32 - $0.39	$9600-$11700
Period 5	180000	180000 rs	$0.07 - $0.09	$25200-$32400
		90000 rt	$0.32 - $0.39	$28800-$35100

Note: Starting with period 5 and in following production years, not all possible root segments are kept and processed. Only that number needed to maintain a constant level of production, 180,000 root segments in this example, are used. The rest are discarded or sold if a market for root segments exists with other nurseries.

FUTURE RESEARCH NEEDS

Optimum stocking for nursery beds has yet to be evaluated. Using our recommended procedure should yield bed densities of about 1.6 rootlings/ft^2 of bed space. More common bed densities for growing quality hardwoods efficiently are in the range of 3-6 trees/ft^2. Planting strategies to achieve such bed densities need to be worked out. The effects of higher bed densities on excess root production, and sprouting vigor will then need to be evaluated.

Herbicide and fertilizer applications need to be studied to find safe chemicals and application rates to use on the beds. Because of the open wounds on the ends of the root segments, the uptake of undesirable levels of soil chemicals can be a more serious problem than in growing seedlings.

As the biological parameters of this technique are determined, we need to continue to study the best ways to mechanize the process and reduce costs. The most significant cost factor is the handling of the roots during the lifting and replanting stages. At least two alternatives need to be evaluated.

Appropriately spaced disc blades might be used to precut the roots in two directions so that root segments could be recovered during lifting, or long pieces of root trimmed during the grading process could be distributed crosswise on the nursery beds and then disced in with blades set at 4-inch intervals.

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A SURVEY OF THE HARVESTING HISTORIES OF SOME POORLY REGENERATED ASPEN STANDS IN NORTHERN MINNESOTA

Peter C. Bates, Charles R. Blinn, and Alvin A. Alm[1]

ABSTRACT.--The increasing demand for quaking aspen in the Lake States illustrates the importance of successfully regenerating existing stands. A number of studies have shown that timber harvesting activities can greatly influence the physiological and environmental factors that control the amount and vigor of suckering. At the same time, forest managers in northern Minnesota have observed instances where some aspen stands have not regenerated satisfactorily following harvest. This paper summarizes the results of a survey comparing the site properties and harvest histories of a number of poorly regenerated stands to successfully regenerated stands in north central Minnesota.

INTRODUCTION

In addition to the large volume of high quality aspen in northern Minnesota, one of the most attractive features of the aspen resource is its ability to vigorously regenerate itself from root suckers following harvest. This makes aspen a relatively simple species to manage with the standard silvicultural prescription consisting of complete clearcutting with the intention of allowing suckers to regenerate the stand.

There has been a considerable amount of research which has identified a number of the most important factors which can affect the suckering response of aspen. These include stand and site characteristics such as the concentrations of growth regulating compounds in aspen roots (Schier 1973), root carbohydrate reserves (Schier 1981, Schier and Zasada 1973, Tew 1970), parent stand density (Graham et al. 1963, Perala 1983, Schier et al. 1985), parent stand condition (Schier 1975), clonal variation (Barnes 1969, Schier 1974), and soil temperature, moisture, and aeration (Maini and Horton 1964).

Timber harvesting activities have a direct impact on some of the above stand and site properties and thus may affect the level of regeneration in some areas. For example, the timing of harvesting activities can influence the root carbohydrates available to developing suckers. In addition, harvesting equipment can greatly influence soil temperature and moisture regimes which can be critical to suckering.

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In recent years, forest managers in northern Minnesota have observed instances where some productive aspen stands have not regenerated satisfactorily following harvest. While at the present time the number of such sites is relatively small, it is important to investigate aspen regeneration on these sites if we are to efficiently and effectively manage our aspen resource for the future.

The purpose of this study was to survey a number of regenerating aspen stands in northern Minnesota to determine if regeneration quality was related to harvest activities and/or site properties. Some of the information required for this survey is not routinely or uniformly maintained by all forest managers; therefore the information for some stands is more precise than for others. While the authors do not feel that this detracts from the potential utility of the survey, they recognize that this survey is limited to identifying general trends and that it is not capable of identifying specific cause and effect relationships.

SURVEY AREA

The survey area is located in north central Minnesota. The climate is continental with warm summers and cold winters. The average length of the frost-free season is about 122 days and the average annual precipitation is about 26 inches (Baker and Strub 1965).

The major soils in the area are derived from a loamy glacial till that is high in shale and limestone which was reworked throughout much of the region by glacial Lake Agassiz. The result is that much of the area is characterized by heavy textured soils on landforms exhibiting little or no relief, although there are some remnant rolling moraines. In some areas there are thin mantles of soil over bedrock and in other areas there are sandy deposits associated with former beaches. Also, there are large expanses of organic soils throughout the region; however, these organic soils generally do not support aspen forests.

METHODS

Specific stands were selected by local forest managers. Each cooperating manager was asked to identify several stands in their region which had been clearcut within the past ten years (since 1979) and had not regenerated satisfactorily. In addition, they were asked to identify satisfactorily-regenerated stands located in close proximity to the poorly-regenerated stands. The intention was not to perform a paired experiment, but rather to select stands representing a range of regeneration qualities. For each stand they were asked to provide the following information:

1. Parent stand characteristics. The age, site index, basal area, and volume/acre of aspen in the parent stand.

2. Harvest history.

    a. Season.--Four seasons were defined:
       1) EARLY SUMMER (June and July),
       2) LATE SUMMER (August through mid- September),
       3) FALL (mid-September through October), and
       4) WINTER (November through May).
       Each stand was assigned a season of harvest based on when the harvesting operation began.
    b. Felling equipment.
    c. Skidding equipment.

Each site was visited and the following data were collected:

1. Topographic class. Each site was classified as either LEVEL (dominated by slopes $\leq$ 3 percent), GENTLY ROLLING (dominated by slopes > 3 and $\leq$ 6 percent), or ROLLING (dominated by slopes > 6 percent).

2. Soil type. The soil at each site was classified in the field as either FINE (texture of clay loam or heavier), FINE/ROCK (texture of clay loam or heavier with bedrock commonly within 5 feet of the surface), COARSE/FINE (twenty to forty inches of sand over clay loam or finer material), or COARSE (texture of fine to medium sand).

3. Regeneration category. The overall quality of regeneration in each stand was classified as either POOR, MODERATE, or GOOD based on visual inspection of the stand with major emphasis on sucker density, crown closure, and sucker form. Fourteen stands were transected using 60, systematically located, mil-acre plots per stand in order to estimate density and percent stocking of aspen stems greater than or equal to 4.5 feet tall for each regeneration category.

4. General observations were recorded concerning site condition and regeneration patterns.

RESULTS AND DISCUSSION

A total of 41 stands were used in the survey. Twenty-three stands were submitted by forest managers as "unsatisfactorily" regenerated, and 18 were submitted as "satisfactorily" regenerated. Of the "unsatisfactorily" regenerated stands, sixteen were placed in the POOR category, six were placed in the MODERATE category, and one was placed in the GOOD category. All 18 of the stands submitted as "successfully" regenerated were placed in the GOOD category. The estimates of stem density and percent stocking are presented in Table 1.

PARENT STAND CHARACTERISTICS

There were no major differences between the parent stand characteristics of the three regeneration categories (Table 2). These data also demonstrate that the stands were generally high quality stands that were not overmature and were sufficiently well stocked to regenerate successfully.

Table 1.--Average density (stems/acre) and percent stocking in each regeneration category[1].

	Regeneration Category		
	Poor	Moderate	Good
(n)	(4)	(4)	(6)
Density	2070	3223	5587
Percent Stocking	53	71	87

[1]Considers only aspen stems $\geq$ 4.5 feet tall.

Table 2.--Mean and standard deviation of parent stand characteristics for each regeneration category.

Regeneration Category		Site Index	Age	Basal Area (ft^2/acre)	Volume (cd/acre)
		Parent Stand Characteristics			
Poor	mean	76	55	115	31
	s	9.8	9.7	19.3	9.1
Moderate	mean	82	52	118	36
	s	11.1	4.8	10.9	4.8
Good	mean	78	54	118	36
	s	11.9	5.9	27.2	6.1

HARVESTING EQUIPMENT

The felling equipment used on these sites is representative of that which is used throughout much of the region. Thirty-one of the forty-one stands were mechanically felled with the rest felled by hand (Fig. 1). The three types of mechanical felling equipment include 1) small, track-mounted shears (SM shear), 2) larger rubber-tired-mounted shears (RT shear), and 3) boom-shears that were mounted on both track and rubber-tired machines (boom shear). There is some evidence that hand-felling resulted in GOOD regeneration more often than mechanical felling, although it does not appear that the type of felling equipment affected regeneration quality.

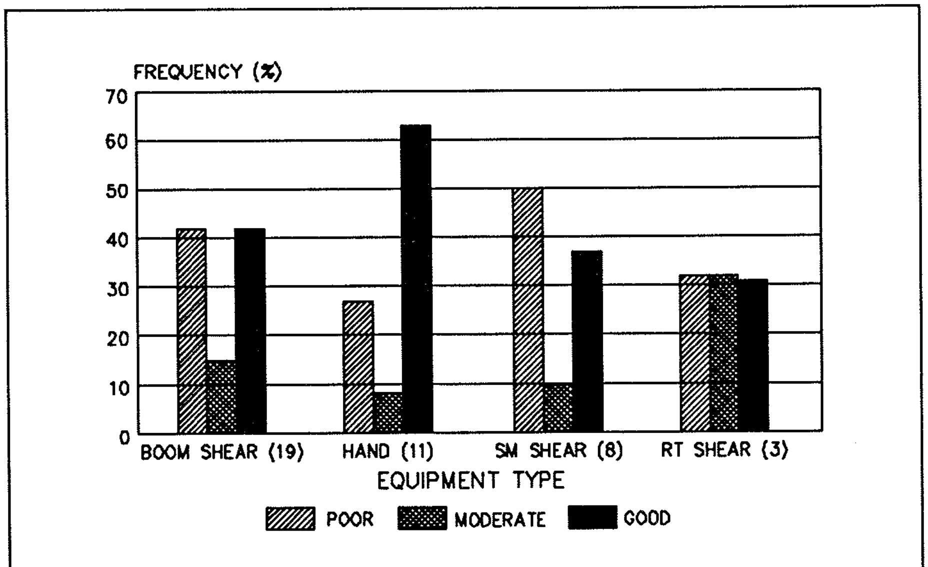

Figure 1.--Frequency of each regeneration category for each type of felling equipment. Numbers in parentheses refer to the number of observations for that equipment type.

The most common size of skidding equipment is that comparable to the John Deere 540B[2] (Fig. 2). There is no clear correlation between size of skidding equipment and regeneration quality. However, this may be partially due to the small number of observations for the larger machines.

SITE CHARACTERISTICS

Aspen in this area grows primarily on the heavier textured soils which may explain why coarser textured soils were underrepresented in our survey (Fig. 3). Again, because of the small sample size for some of the soil categories, it is difficult to evaluate how soil type by itself influences regeneration quality. However, in terms of topographic class, there is evidence that POOR regeneration was more common on level sites and GOOD regeneration was more frequent on rolling sites (Fig. 4).

SEASON OF HARVEST

The results for season of harvest are presented in Figure 5. Most of the POOR regeneration was associated with early summer harvests. Also, the frequency of GOOD regeneration increased on sites harvested later in the year.

To further examine the above observations, the regeneration categories of the different topographic classes were compared considering only the early summer harvests (Fig. 6). These results support the suggestion that regeneration problems are potentially most severe on level sites that are harvested early in the summer.

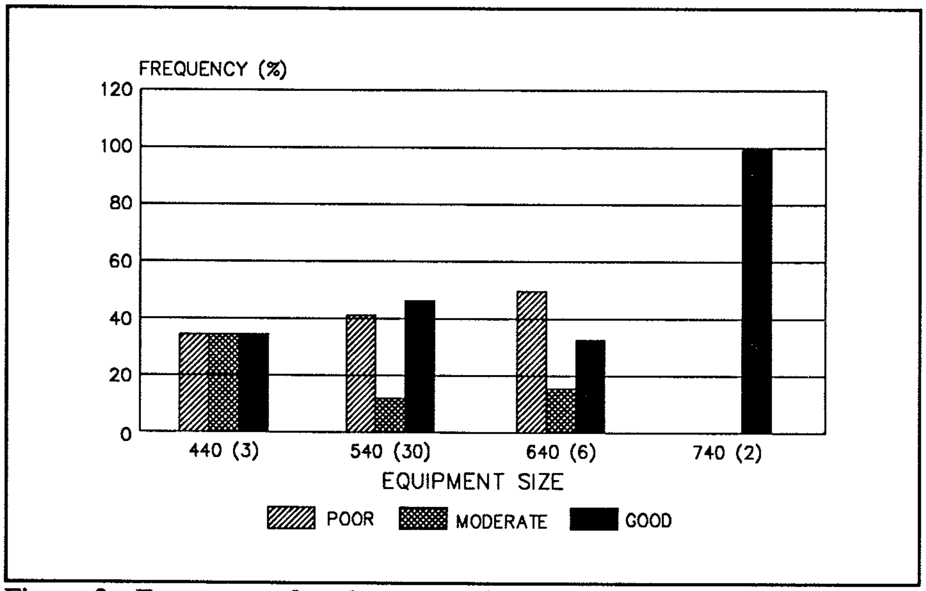

Figure 2.--Frequency of each regeneration category for each size of skidding equipment. Numbers in parentheses refer to the number of observations for that equipment size.

[2]Use of tradenames does not imply endorsement by the authors, but is merely for the convenience of the readers.

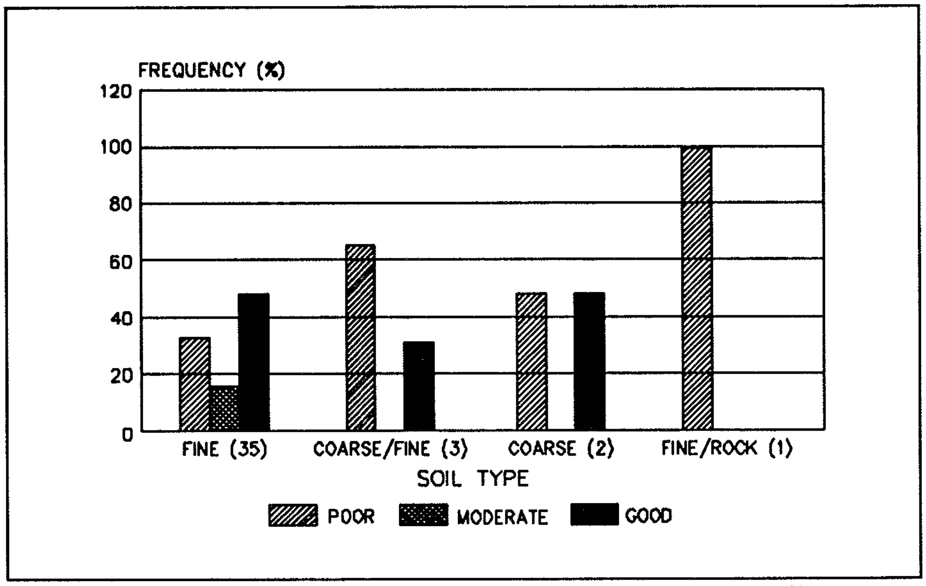

Figure 3.--Frequency of each regeneration category for each soil type. Numbers in parentheses refer to the number of observations for that soil type.

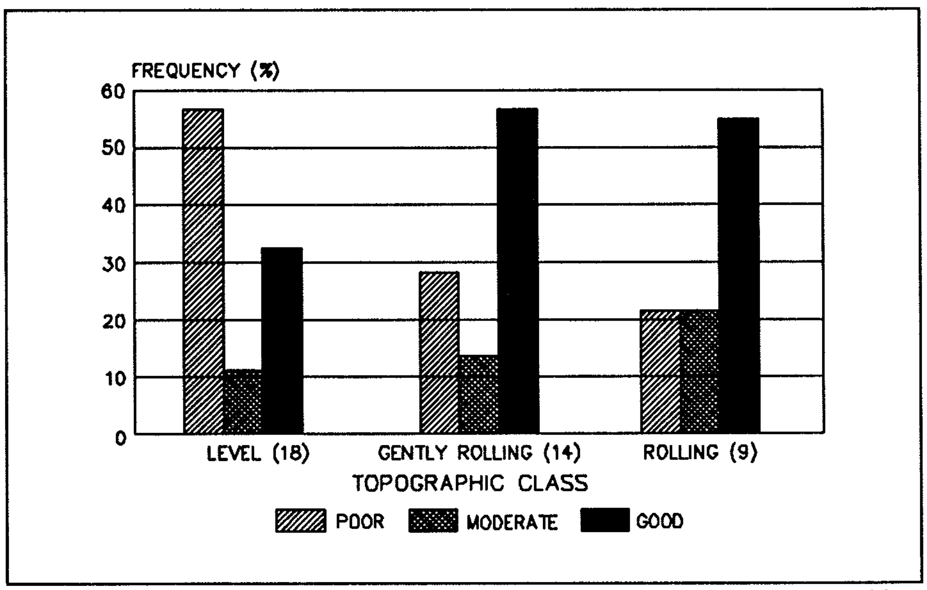

Figure 4.--Frequency of each regeneration category for each topographic class. Numbers in parentheses refer to the number of observations for that topographic class.

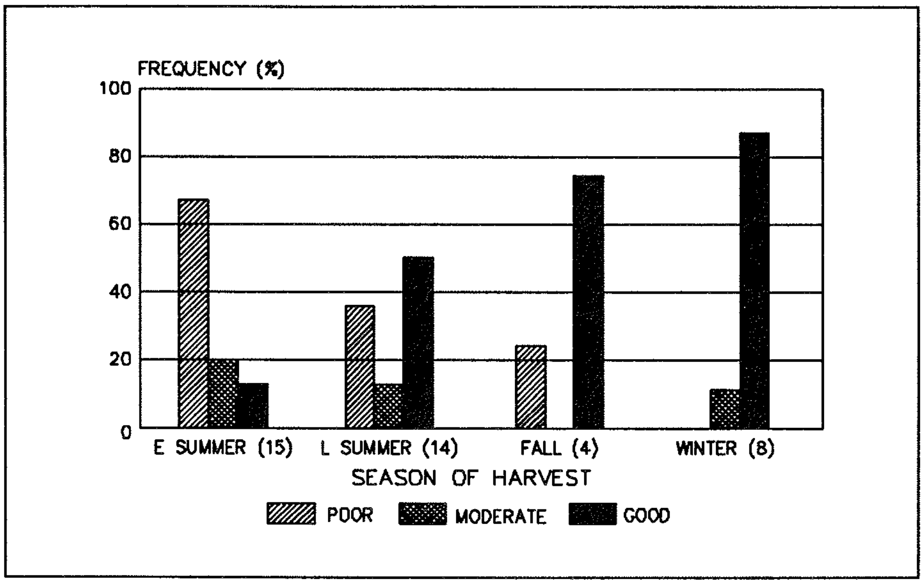

Figure 5.--Frequency of each regeneration category for each season of harvest. Numbers in parentheses refer to the number of observations for that season.

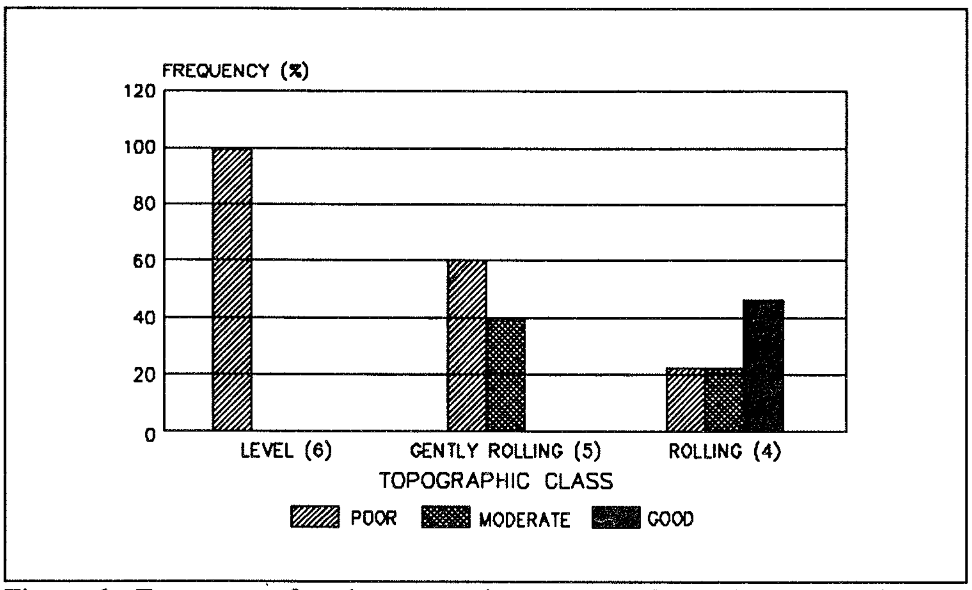

Figure 6.--Frequency of each regeneration category for each topographic class for early summer harvests only. Numbers in parentheses refer to the number of observations for that topographic class.

MULTIPLE ENTRY INTO A STAND

The survey indicated that managers should consider the effects of repeated entry into a stand. Eleven of the stands were entered on more than one occasion, often with the removal of different products at each period of entry. Six of these (55 percent) were in the POOR category, one was MODERATE and four were GOOD.

GENERAL OBSERVATIONS

The following observations were not specifically quantified, but were noted during field inspection of the sites.

Trafficking

In virtually all of the stands, good quality regeneration was lacking in areas that had been obviously trafficked. This was particularly true in MODERATE and GOOD stands where skid trails and landings were easily identifiable by the lack of regeneration. Conversely, in many of the POOR sites it was equally clear that patches of successful regeneration were associated with areas that had not been trafficked, such as, the back edges of sites and areas where equipment obviously went around snags and stumps.

Rutting

Rutting was considered to occur where harvesting equipment broke through the organic soil surface and left definite depressions (ruts) in the mineral soil. In many cases, areas of POOR regeneration were associated with excessive rutting. There were no sites exhibiting widespread rutting that had GOOD regeneration.

Swales/Depressions

Much of this landscape is quite wet and virtually all of the stands contain swales which support vegetation ranging from cattails to ash and balm of gilead. These depressions generally lack aspen, suggesting that these areas do not contain aspen roots and would not sucker regardless of how or when the stand was cut.

These areas stand out as obvious gaps in young sucker stands and upon casual inspection may lead some observers to conclude that they are due to harvesting impacts. However, it did appear that trafficking through and around swales when they were not frozen could increase their size. This situation might be worsened by the increased use of larger, more powerful machinery which makes it possible to operate under marginal conditions.

POSSIBLE CAUSES OF REGENERATION PROBLEMS

After concluding this survey, there appear to be several factors which alone, or in combination, might explain the occurrences of POOR regeneration observed.

Excessive Wetness

The high incidence of POOR regeneration on level sites seems to support this contention. Many of the level sites are poorly drained and have high water tables, particularly in the early summer before they have had a chance to dry out after snow-melt. These sites may be too low in soil oxygen when harvested at this time to be able to sucker; harvesting at a later date when the soil had an opportunity to dry out may yield better regeneration.

Compaction And Rutting

Widespread trafficking can compact and smear the soil surface which reduces porosity and decreases the rate of water movement through a soil. Also, many of these sites have a very subtle surface drainage pattern which might be disrupted by rutting. Both of these can result in increased wetness, particularly on poorly drained sites. Soils become more susceptible to rutting and compaction as their moisture content increases. Consequently, many of these soils are most susceptible to rutting and compaction in the early summer.

Physical Damage To Aspen Roots

Aspen roots are characteristically shallow, and are often present in the humus layer above the mineral soil. Thus they are very susceptible to damage by harvesting equipment which can either kill root segments or open up wounds which can serve as entry ports for various pathogens. Obviously, when rutting is occurring, aspen roots are being broken and wounded. However, damage may also occur in the absence of any rutting. This could explain why some areas of POOR regeneration exist in skid trails on better drained sites that are not rutted and do not become saturated.

SUMMARY

Aspen is a species that regenerates well through complete clearcutting. In a few instances certain harvesting activities may influence its regeneration ability. While this survey did not identify all possible areas of concern, it did seem to indicate several situations that may be particularly sensitive to regeneration problems. These include:

1. Stands growing on level, poorly drained soils.

2. Stands harvested in early summer.

3. Stands where there is widespread trafficking that might damage the shallow aspen roots.

4. Repeated entry into a stand.

Managers should consider these factors when prescribing and monitoring aspen harvests.

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A SUMMARY OF ASPEN GENETIC IMPROVEMENT RESEARCH AT THE UNIVERSITY OF MINNESOTA

Neil A. Anderson, David W. French, Glenn R. Furnier, Wesley P. Hackett, and Carl A. Mohn[1]

ABSTRACT.--Aspen genetic improvement research at the University of Minnesota includes selection and testing of superior genotypes, the use of molecular genetic markers to assist tree improvement efforts, the development of methods for introducing foreign genes into aspen and to propagate these genotypes by tissue culture. Gene expression studies are aimed at understanding the response of aspen to wounding. Variation in fungi causing canker diseases is being examined and the implications of this variation for tree improvement are being assessed.

EVALUATION OF NATIVE POPULATIONS IN FIELD TESTS

Evaluation of aspen by the College of Natural Resources began in the late 1950's with the introduction of material from the Cabot Foundation program at Harvard University to Minnesota by Scott Pauley. Test or arboretum plantings established since then have included Populus tremuloides, P. grandidentata, P. tremula, P. alba, and numerous interspecific hybrids. Field testing has been limited in scope because of the costs of establishment and the limited interest of cooperators.

Recent work has concentrated almost exclusively on native populations of P. tremuloides. One field test planted in the early 1970's was designed to examine variation among geographic sources. While that test had unsatisfactory survival, the early height data (Fig. 1) indicate strong genetic differences among geographic sources. These data are not definitive since sample sizes were small and testing was limited to a single site (Itasca Co., Minnesota). Data from a single test site cannot allow us to determine whether poor growth of some sources is due to overall poor genetic growth potential or to genotype-environment interactions. The answers to this and other questions are essential to the effective selection of materials for any tree improvement program (hybrid or otherwise).

Two other small tests initiated in the late 1970's are aimed at evaluating genetic variation in P. tremuloides at the individual tree level. One is a clonal test established with rooted cuttings and the other is a test of full-sib families produced by controlled pollinations. The tenth year data from both tests indicate extensive genetic variation in the native aspen population. The clonal test involved 35 clones from throughout Minnesota selected for apparent vigor and freedom from cankers. Spacing in the field test was close (5' x 5'). At ten years, survival was 78 percent in the three replications evaluated and test means for height and diameter were 34 feet and 3.0 inches, respectively. Mean volume per stem of clones ranged from 17 percent to 200 percent of the test mean (Fig. 2).

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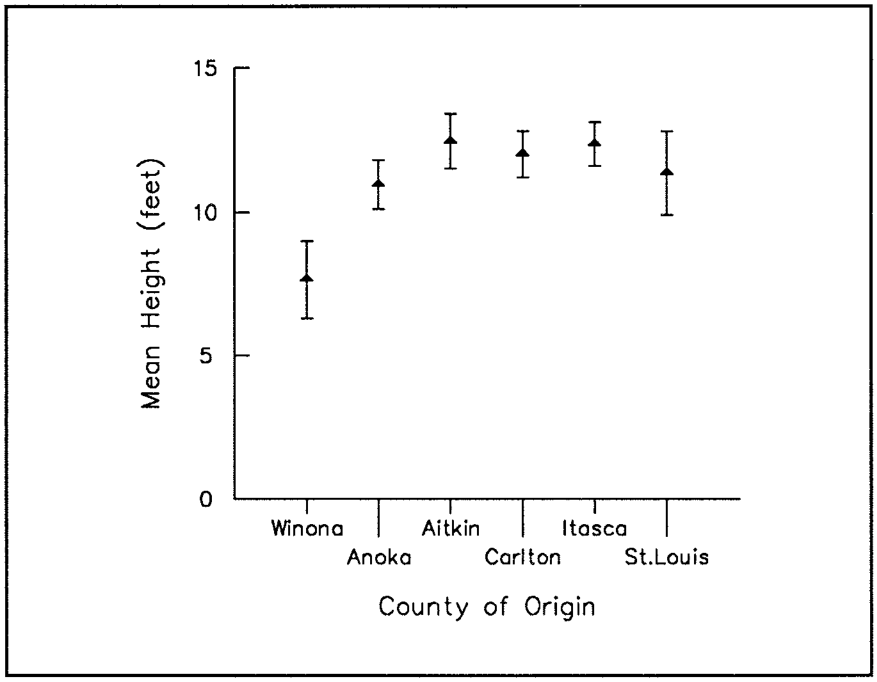

Figure 1.--Variation in early height growth of open-pollinated Populus tremuloides seedlings from six areas in Minnesota.

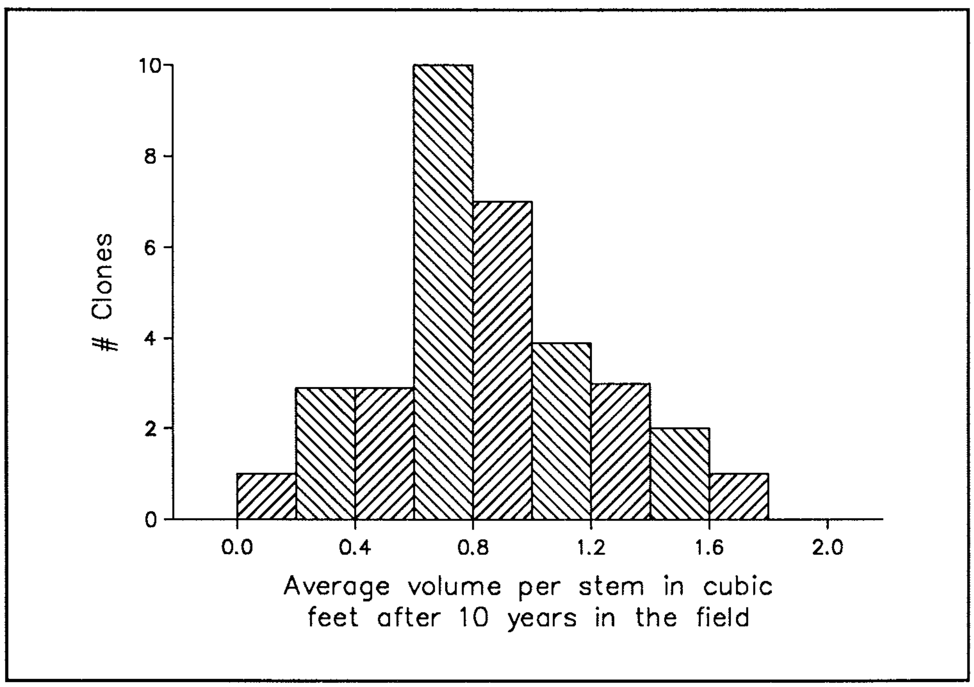

Figure 2.--Distribution of mean tenth year total volume per stem for 35 native Populus tremuloides clones planted at 5 ft. x 5 ft. spacing in Itasca County, Minnesota.

Figure 3 illustrates these data on a volume growth/acre/year basis. The potential of selection of native P. tremuloides for increased productivity is obvious from these data. We should not overlook this valuable genetic resource if we wish to develop well-adapted, improved aspen planting materials with a broad genetic base.

THE USE OF MOLECULAR GENETIC MARKERS IN ASPEN IMPROVEMENT

The advent of molecular genetics has provided us with a new set of tools that can be useful in tree improvement programs. Particularly useful has been the development of methods for assaying many genetic markers. Unlike traits such as growth, these markers are simply inherited and there expression is affected very little by the environment. This makes them relatively easy and rapid to assay.

The first type of genetic markers we are using is allozymes, which are alternate forms of proteins encoded by the same gene. We grind a small amount of leaf, bud, or root tissue in a buffer, place this extract on a starch gel, and subject it to an electric current. The proteins migrate at a certain speed based on their charge, size, and conformation. We then stain slices of this gel for specific proteins. Proteins that have migrated to different positions represent different genetic variants. By assaying a number of different protein stains, we can determine the genotype of an individual at a number of loci (genes). We are currently evaluating variation at eleven allozyme loci in a statewide sample of P. tremuloides. We expect this study to provide insight into patterns of genetic variation in the species in Minnesota.

An even more important application of these markers is as a tool for identification of clones in a breeding program and in field studies. In a preliminary study involving 14 allozyme loci, none of the 35 clones examined exhibited the same genotype. These genetic markers will allow us to confirm that clones have been planted in the correct positions in field tests and will permit unique identification of

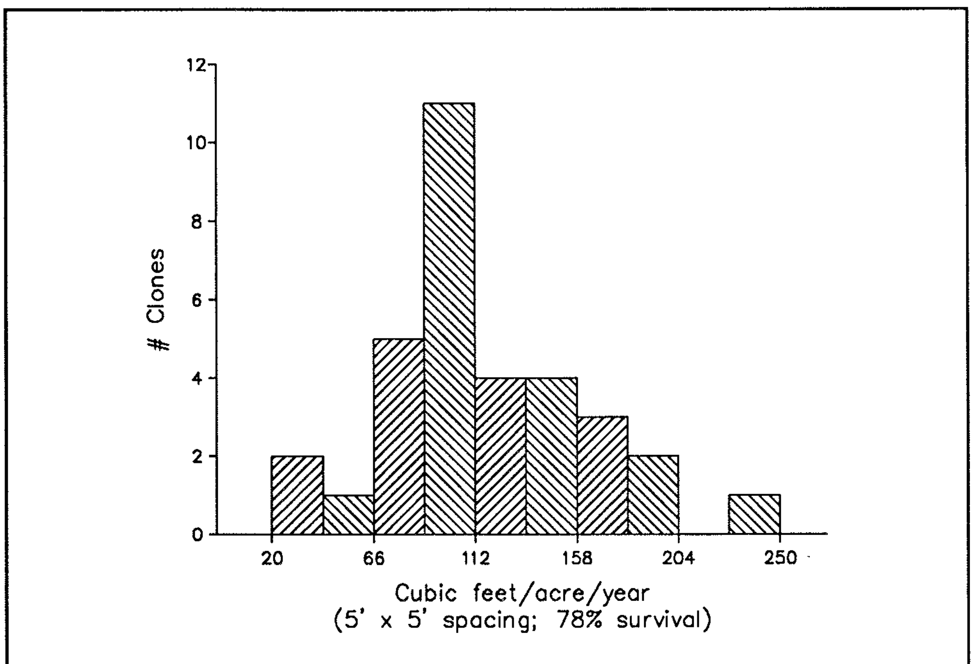

Figure 3.--Distribution of estimated annual increment over ten years growth for 35 native Populus tremuloides clones planted at 5 ft. x 5 ft. spacing in Itasca County, Minnesota.

clones for patent purposes. Since these markers are simply inherited, they can be used to confirm the parentage of controlled crosses in a breeding program, ruling out the possibility of pollen contamination. This is similar to the use of blood types for determining paternity in humans.

While allozyme assays are rapid and quite useful, they may not always provide enough genetic markers to uniquely identify all individuals. We can then resort to directly examining variation in the DNA sequence by the use of restriction enzymes. These enzymes have the property of cutting DNA at unique recognition sites. Two individuals may differ by a mutation at this recognition site, with one genotype being cut by the enzyme at that site and the other not being cut. By separating the cut DNA on a gel under an electric current, similar to the manner in which we separate allozymes on a gel, we can examine the number and sizes of DNA fragments. Any differences observed on the gel represent genetic differences between two individuals. The power of this technique is the availability of many restriction enzymes that cut at a wide variety of recognition sites and the ability to assay many more genes than those for which we have available allozyme protein stains. This use of restriction enzymes to assay variation in DNA sequences, also known as DNA fingerprinting, is receiving increasing use in uniquely identifying individual people in criminal cases.

We are currently using DNA restriction analysis to develop genetic markers that will distinguish P. tremuloides from P. grandidentata. While they often can be distinguished by morphological characters, the intraspecific variability in these traits can make certain identification difficult at times. Natural hybrids between these species have been reported, but genetic markers have not been available to confirm that these are indeed hybrids. The ability to positively identify selected material entering a tree improvement program is important.

MICROPROPAGATION, GENETIC TRANSFORMATION, AND GENE EXPRESSION

The ability to propagate genotypes rapidly and inexpensively, while maintaining genetic fidelity is important to research and could impact commercial planting programs. Tissue culture work with aspen has been underway at the University for just over a year. We are investigating aspects of micropropagation and in vitro development using a variety of tissue types, including callus, leaf discs, and stem nodes. Materials have originated from mature trees in the field or from suckers grown from root segments in the greenhouse. While there are strong clonal differences in the response of explants to culture, we have been able to initiate shoots on explants of all but two of the approximately 40 clones we have examined. In general, leaf discs have been the most reactive type of explant. The question of genetic fidelity of plantlets of this origin has yet to be addressed.

In vitro propagation systems are critical to the success of planned genetic transformation studies. P. tremuloides is one of the species for which we are developing Agrobacterium mediated transformation systems. DNA is inserted into Agrobacterium tumefaciens, which then introduces the DNA into the aspen genome. At present, we are assessing the ability of five A. tumefaciens strains to infect and transform P. tremuloides. The effects of two different inducer compounds are also being evaluated. Three of the A. tumefaciens strains are wild type and two are engineered. A few putatively transformed plants have been produced and we are in the process of confirming their genetic modification.

Once genetic transformation systems are developed, we will be confronted with the question of which genes we may want to introduce into aspen. Bacterial genes coding for herbicide tolerance and insecticidal toxins have been introduced into plants with promising results and may be of future use in aspen. Unfortunately, we know very little about the biochemical, physiological, and molecular genetic mechanisms underlying traits of economic importance in trees. We are initiating a study to examine changes gene expression in response to wounding in P. tremuloides. We are particularly interested in the genetic basis for differences between clones that are able to rapidly close wounds by callus production and clones that are not as rapid. This rapid callus formation may confer increased tolerance of attacks by insects and canker diseases.

Some years ago it was thought that there were several species of Hypoxylon on a reasonably wide range of tree species. Later the genus was revised, combining several species into one, H. mammatum. If tree breeders needed to be concerned with only one rather invariant fungus species, their objective of disease resistance could be achieved without being concerned about diversity in the pathogen. However, the experience of agronomic crop breeders suggests that this will not be the case.

H. mammatum isolates have since been found to cause lethal cankers on Salix daphnoides and other willow species. Isolates of H. mammatum most commonly collected from aspen have not caused cankers on willows. These observations indicate that there are at least two pathogenic races or varieties of the H. mammatum. Further investigations have shown that there are at least four distinct varieties of the fungus that vary in their pathogenicity on aspens and willows. Early results indicate that these cankers are sufficiently distinct to allow the identification of the fungus variety present on a plant. The presence of multiple varieties of H. mammatum means that aspen genotypes selected for propagation will have to be screened for resistance to a number of varieties of the fungus, rather than just to one isolate.

Cryptosphaeria populina and Encoelia pruinosa (Cenangium singulare) are two other species of fungi that cause cankers on aspen. Sooty-bark canker (E. pruinosa) is the most lethal canker disease of aspen in western North America. There is considerable doubt, however, as to the importance of these fungi in the Lake States, since studies to date have failed to clearly demonstrate conditions under which these species are serious pathogens in this region. They have, however, both caused mortality in the Lake States under certain circumstances. Inoculation studies using a variety of aspen and fungal genotypes are underway. We need to know the full potential of these fungi if we are to select aspen genotypes that will produce trees that grow well and are resistant to lethal or distorting canker diseases.

ACKNOWLEDGMENTS

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DISEASE RESISTANCE IN A WILD SYSTEM:HYPOXYLON CANKER OF ASPEN

Michael E. Ostry and Neil A. Anderson[1]

ABSTRACT.--The Hypoxylon canker-aspen disease system is an extremely complex host-parasite interaction that involves many biological and environmental factors. Our research of the infection process has helped to explain key variables in host resistance to this disease. Several types of resistance are important including resistance to infection, resistance to canker development, and spatial resistance that is influenced by stand density factors.

INTRODUCTION

Plant pathologists have the responsibility of screening the world's food and fiber crops to identify genes that confer disease resistance. The use and misuse of these genes have far-reaching consequences. Most of the host-pathogen systems in agriculture involve either an introduced host or a pathogen, or both. Much of what we know about disease resistance is from situations where one or both partners in the parasitic relationship have been introduced.

Host-parasite interactions of indigenous systems may differ from systems in which one or both partners have been introduced. For example, aeciospores of the introduced white pine blister rust fungus (Cronartium ribicola) can spread for miles from white pine to ribes plants (Anderson 1973), but aeciospores of the indigenous sweetfern rust (C. comptoniae) travel only a few feet from the native jack pine to the native sweetfern or sweet gale (Anderson and French 1964). Urediospores of the introduced wheat stem rust fungus (Puccinia graminis var. tritici) can spread in great leaps from Mexico to Canada (Stakman and Harrar 1957), while some rusts on native plants in northern latitudes complete their life cycle on an alternate host only a few meters away (Savile 1976).

The best genetic explanation of host-pathogen interactions is the gene-for-gene theory of Flor (1956). In this hypothesis, genes for virulence in the pathogen are matched against specific disease resistance genes in the host. However, all host-pathogen systems that have conformed to this theory have included a highly cultivated host plant (Barrett 1985). Most biologists now consider Flor's theory a genetic critique of modern agriculture where vast acreages are planted with a crop that has limited genetic diversity. In modern agriculture, breeders must meet the challenge of the ever-changing pathogen populations that overcome host resistance by deploying new resistance genes.

To gain information on the nature of disease resistance in a wild system we chose to study the aspen-Hypoxylon canker disease system. Populus tremuloides Michx. has the widest range of any tree species in our hemisphere and is rich in genetic diversity. Aspen clones differ in many traits (Cheliak and Pitel 1984, Hyun et al. 1987), including their resistance to diseases (Capony and Barnes 1974). Clones of 200 acres or more occur in western U.S., and clones of 0.1 to 3 acres occur in the Lake States (Kemperman and Barnes 1976).

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Hypoxylon mammatum (Wahl.) Mill. is the most destructive pathogen of young aspen in the Lake States. Much has been learned about the aspen-Hypoxylon relationship, but many critical gaps must be filled before effective management strategies can be developed to minimize the impact of this disease (Manion and Griffin 1986). One missing piece of information is how trees become infected.

The objective of our research was to study the infection process of Hypoxylon in aspen. Our goals were to determine the nature of resistance of some aspen clones to the fungus and to reconcile laboratory research results on the host and pathogen with field biology studies.

DISEASE CYCLE

Many investigators have studied the infection process of Hypoxylon. Classical signs and symptoms of the canker disease include a dead branch or dead branch stub in the center of the canker and marbleized yellow-black decayed xylem tissue behind the canker face. Although the fungus is a wound parasite (Bier 1940), some infections can be found on trees with no observable injury.
Studies have shown the green layer in the aspen bark contains pyrochatechol, two glycocides, and a phenol that are fungistatic to the spores and mycelium of Hypoxylon (French and Oshima 1959, Hubbes 1964, 1966). The fungus produces a toxin that prevents callus formation and detoxifies the fungistatic chemicals in the green bark layer (Schipper 1978). H. mammatum destroys phloem tissues, but has limited enzymes to break down sucrose, the sugar transported in the phloem (Anderson and Schipper 1975). The fungus does, however, have enzymes that break down cellulose and cause wood decay.

In our studies, we have associated insect oviposition wounds with infection of aspen by Hypoxylon. Wounds made by cicada (Magicicada septendecim L.), poplar-gall saperda, (Saperda inornata Say), and tree hoppers (Telamona tremulata Ball) are entry courts for Hypoxylon (Anderson et al. 1979, Ostry and Anderson 1983, 1986). We have examined cross-sections of naturally infected aspen S. inornata galls that had only slight external disease symptoms. In all cases the xylem tissue showed advance symptoms of decay and only small portions of the phloem were decayed. Scanning electron microscopy revealed that the fungus formed extensive aggregated sheets of hyphae before invading the phloem. Cankers have developed on aspen branches inoculated with Hypoxylon ascospores through saperda galls (Anderson and Ostry 1983), indicating that ascospore infection of insect wounds may be a major means of entry.

The relationship between certain wood-boring insects of aspen and infection by Hypoxylon has provided us with an insight into the infection process, the stand density-canker incidence phenomenon, the pattern of infection on individual trees, fluctuation in canker incidence, the distribution of the disease in the Lake States, and host resistance to this disease. Downy woodpeckers (Picoides pubescens) frequently forage on and around cankers on aspen in search of larvae of various wood-boring insects. Woodpeckers also forage on Saperda galls, resulting in additional wounds on aspen branches as the birds extract larvae, and perhaps, serve as vectors for the fungus (Ostry et al. 1982).

PATHOGEN VARIABILITY

The growth characteristics and virulence of several H. mammatum isolates collected throughout the north central U.S. varied greatly, indicating the presence of several biotypes (Anderson and Schipper 1975). All of the isolates were pathogenic, but, large differences were present in growth rate of the fungus in vitro and in canker elongation when they were inoculated into aspen. In our work, up to one-third of the isolates obtained from single ascospore cultures were slow-growing mutant types. However, when we isolated from cankers in the field, we obtained only wild-type fast-growing isolates. This indicates that the fungus has an effective way of eliminating mutant types and only fast-growing types survive in nature.

HOST RESISTANCE

To study the apparent genetic differences in aspen susceptibility to Hypoxylon, we established two aspen plantations in Minnesota and Wisconsin. Controlled crosses were made of parent trees selected from highly infected clones and canker-free clones throughout Minnesota. Trees from 85 different crosses were planted. Parent trees propagated from root cuttings were also included in the plantings. Nearly 2,000 trees have been planted since 1965. The incidence of Hypoxylon canker varies between progeny of the various parents. We identified about 50 trees that are superior in form and insect and disease resistance. These trees are being clonally propagated by using tissue culture techniques, and they will be field tested on several different sites.

Resistance of aspen to Hypoxylon includes resistance to infection and subsequent canker development. Superimposed on these resistance mechanisms is the inherent resistance provided to aspen growing in dense stands. This type of resistance has been called spatial resistance, which includes the many environmental and biotic factors associated with stand density that affect disease expression toward decreased disease incidence (McNabb et al. 1982).

STAND DENSITY

Several investigators have associated higher canker incidence with low stand density and trees along stand edges (Day and Strong 1959, Anderson 1964, Anderson and Anderson 1968, Bruck and Manion 1980, Anderson and Martin 1981). In a study designed to determine the relation between the incidence of Hypoxylon canker and the presence of branches on aspen, pruned trees had fewer lower bole cankers (Ostry and Anderson 1979). Aspen in thinnned or understocked stands have branches that persist longer than in dense stands, increasing the chance of being infected by Hypoxylon. Other factors associated with stand density that have been suggested as favoring infection include decreased soil moisture and nutrients, and increased sunlight and air movement in open stands. The task of determining relations between site variables is further complicated by clonal differences in susceptibility to the fungus. We have data that indicate that the clones in study plots result in greater differences in canker incidence than the thinning and fertilization treatments applied.[2]

SUMMARY AND MANAGEMENT IMPLICATIONS

Our studies over the past two decades have confirmed that resistance in aspen to Hypoxylon is complex. A specific type of wound is required for infection by the fungus, and certain environmental conditions are required for disease development. The tree responds to wounds by forming callus that closes the wounds, preventing infection or inhibiting canker expansion. Clonal differences in these responses are common and indicate that it may be possible to select superior genotypes. Stand density influences the incidence of the disease through several interacting factors, and this spatial resistance may provide a possible management strategy to minimize the disease impact.

Because aspens grow as a mosaic of relatively small clones in the Lake States, clone identification is important. This is especially critical in research and inventory plots to account for variability in treatment effects, data on tree growth, or insect and disease impact. Several tree traits can be used to distinguish clones (Barnes 1969). We are also using aerial photography to assist in the delineation of clone boundaries within our research plots. Silvicultural methods for expanding clones of superior aspen may be important in the future as part of intensive management strategies for the aspen resource.

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[2]M.E. Ostry and N.A. Anderson, North Central Forest Experiment Station, St. Paul, MN., unpublished data.

Tissue culture techniques are being developed that will allow clonal multiplication of selected aspen genotypes for planting. By planting the same aspen clone on several different sites, we will learn how site factors influence aspen growth and the incidence and severity of insects and diseases. At the present time, clonal variability makes it difficult to sort out the important factors that contribute to the resistance or susceptibility of aspen to damaging agents.

Much research remains to be done before we can develop sound intensive management practices for aspen. With the increasing interest in aspen come the challenge and opportunity to increase the quantity and quality of our stands. With a multidisciplinary team approach, including people skilled in silviculture, genetics, insect and disease control, and use of new tissue culture and molecular techniques, we can begin to improve upon our management of aspen and maintain this important resource for its many uses.

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THE LAKE STATES' ASPEN RESOURCE REVISITED: MID-1960s-1987

John S. Spencer, Jr., Earl C. Leatherberry, Neal P. Kingsley[1]

ABSTRACT.--Area of the aspen forest type in the Lake States declined from 13.2 to 11.8 million acres between the mid-1960s and 1987, a 10-percent loss. During the same period volume of aspen growing stock increased from 7.1 to 8.7 billion cubic feet, a gain of 22 percent. Forty-six percent of the area is in poletimber stands, and 48 percent of the aspen type is owned by nonindustrial private parties. Estimated timber removals of aspen in 1987 were greater than net growth in each of the Lake States. Information for 1987 is based on computer updated inventory data.

INTRODUCTION

When you mention the Lake States of Michigan, Minnesota and Wisconsin, a forester's thoughts usually turn to aspen. Yet, aspen was not always the dominant species in this region. In fact, in much of the region it was a minor, largely overlooked species in the early post-settlement forest. Wisconsin provides an excellent example of the rise of aspen. In a description of the State's early forests, aspen is not even mentioned (Anon. 1956). And, a map of the original vegetative cover of Wisconsin, developed by Professor Robert W. Finley of the University of Wisconsin and based on original survey notes from 1832 to 1866, shows only two small patches of the aspen type in northwestern Wisconsin. Most of the map shows northern hardwoods and pine in the northern part of the State with oaks, maple, beech, and basswood in the south.

Lumber production in Wisconsin peaked in 1899 at 3.3 billion board feet, of which 2.8 billion was softwoods, mostly pine (Anon. 1956). By contrast, Wisconsin lumber production stood at 534 million board feet in 1986 (Unpublished Forest Inventory and Analysis data). Hardwoods accounted for 87 percent of this total. In the late 19th century Wisconsin's forests were being exploited so rapidly that Roth, in an 1898 report on the forests of northern Wisconsin, wrote:

> The pine has disappeared from most of the mixed forest and the greater portion of the pineries proper has been cut. There is today hardly a township in this large area where no logging has been done. In addition to this, the fires, following all logging operations or starting on new clearings of the settler, have done much to change these woods. Nearly half of this territory has been burned over at least once: about 3 million acres are without any forest cover whatever, and several million acres more are but partly covered by dead and dying remnants of the former forest (Anon. 1956).

Following the logging boom and the fires in the late 1800s and early 1900s, aspen moved in to reclaim the better pine sites and much of the hardwood area. Not only did the species come to constitute a very large share of timber volume and forest area, but it caused a significant change in

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the forest industry of the Lake States. Today fiber is the important forest product in the region. Sixty percent of the wood cut in the Lake States is pulpwood, used for manufacturing either woodpulp or flakeboard. Half of the more than 7 million cords of pulpwood produced annually in the Lake States is aspen. Thus, aspen has gone from a minor weed species to the mainstay of a dynamic forest industry. What is its current status and extent? And, what does its future look like? The following glimpse of the resource, based on past statewide forest inventories and computer updates to 1987, provides our best estimate of the present aspen situation in the Lake States.

AREA

In North America the natural range of aspen extends throughout all provinces and territories of Canada and the northern tier of the Northeastern States, westward to the Lake States and then to the mountains of the Western States. But, in the United States, the largest concentrations of aspen are found in the Lake States and there, aspen plays a very important economic role.

Recent forest inventories were completed for each of the Lake States (Michigan in 1966 and 1980, Minnesota in 1962 and 1977, and Wisconsin in 1968 and 1983). To compare inventories we grouped data for the earlier dates under the heading "mid-1960s," and data for the latter dates under "early 1980s." Areas for 1987 are from Smith and Hahn (1986, 1989) and Hahn and Smith (1987), which reported updated statistics for each of the States. Forest type areas for 1987 are based on analyses of past area trends.

Between the mid-1960s and 1987, the area of timberland in the aspen forest type declined from 13.2 to 11.8 million acres, a 10-percent loss (Table 1).

Area of the aspen forest type is declining primarily because aspen, a pioneer species, is being replaced by other species when management favoring aspen is not practiced. This occurs as plant succession continues on the site. Stands older than about 60 years are considered overmature, and they tend to decay or break up quickly. As the mature stands deteriorate, the more shade tolerant species present in the understory, such as maple or balsam fir, replace the aspen.

Poletimber and sapling-seedling sized stands dominate the region's aspen type. In the Lake States 5.5 million acres (46%) of the aspen type are in poletimber stands; 4.9 million acres (42%) are in sapling-seedling stands; and 1.4 million acres (12%) are in sawtimber stands (Fig. 1).

Table 1.--Area of timberland in the aspen forest type, Lake States, mid-1960s, early 1980s, and 1987.

State	Mid-1960s	Early 1980s	1987	Change
	-------------------(In thousand acres)-------------------			(Percent)
Michigan	4,150.4	3,408.1	3,325.4	-19.9
Minnesota	5,399.8	5,328.2	5,278.0	-2.3
Wisconsin	3,664.6	3,261.5	3,226.3	-12.0
Total	13,214.8	11,997.8	11,829.7	-10.5

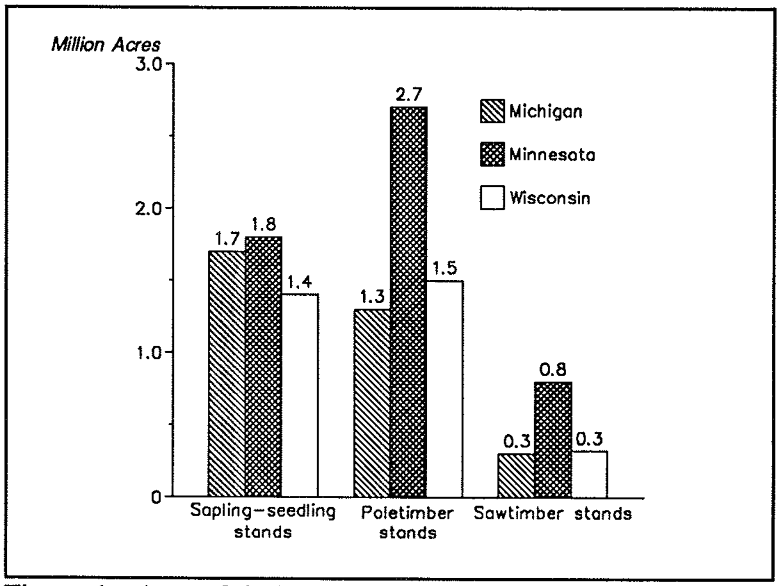

Figure 1.--Area of timberland in the aspen forest type by stand-size class and State, Lakes States, 1987.

Poletimber and sapling-seedling stands dominate because aspen is a short-lived species that usually does not attain large diameter size.

The present age class distribution of the aspen type is not ideal for several reasons. First, area of the 21-to-40-year class will not be sufficient to produce the volume of aspen harvested presently, assuming growth does not increase appreciably (Table 2). The 21-to-40-year-old aspen stands are most likely to be harvested during the next 20-year period, when the supply of aspen will be stretched thinnest. There is also a substantial area (2.3 million acres) of stands more than 60 years old. These are stands where "break up" will soon begin or has already begun, and where timber is least likely to be commercially usable because of decay.

Table 2.--Area of timberland in the aspen forest type by stand-age class and State, 1987.

Stand-age Class (years)	Total	Michigan	Minnesota	Wisconsin	Percent
	------------------------(In thousand acres)-------------------				
1-20	3,367.7	1,107.7	1,065.4	1,194.6	28.5
21-40	2,411.5	687.4	951.5	772.6	20.4
41-60	3,785.0	822.1	1,927.8	1,035.0	32.0
61-80	1,872.9	563.9	1,123.3	185.7	15.8
81-100	308.3	108.8	161.2	38.3	2.6
101-120	76.1	30.8	45.3	--	0.6
121-140	4.7	4.7	--	--	0.1
141+	3.5	--	3.5	--	--
Total	11,829.7	3,325.4	5,278.0	3,226.3	100.0

For comparison purposes, the textbook "normal" or "fully regulated" aspen forest of 11,828 thousand acres would have three 20-year age classes of 3,943 thousand acres each, with no area more than 60 years of age. This "normal" forest is ideal only for species managed by even-aged techniques, such as aspen, and only if the entire area is devoted to commercial timber production. The Lake States may never achieve, or wish to achieve, this "normal" situation. In 1987, 49 percent of the stands there were 40 years old or younger; 32 percent were between the ages of 41 and 60 years; and 19 percent were more than 60 years.

Figure 2 illustrates the aspen age class distribution in 1987 and theoretical distributions in 2007 and 2027 if the following assumptions are made: 1) Ninety percent of the aspen removals volume will come from the aspen forest type; the remaining 10 percent will come from aspen in other forest types. 2) The 1987 (1983-1986) aspen removals volume will increase 10 percent by 2007, then increase another 10 percent by 2027. 3) All land will be available for timber harvesting. 4) The oldest stands will be harvested first. 5) Net growth on stands harvested will increase, resulting in harvest volumes per acre that are approximately 30 percent greater in 2007 than in 1987, and then level off. 6) All of the growing-stock volume in stands aged 41 to 60 years will be merchantable, compared with 75 percent of the volume in stands aged 61 to 80, 50 percent of the volume in stands aged 81 to 100, and none of the volume in stands more than 100 years old.

Under these hypothetical assumptions, the distribution of age classes improves and closely approaches the "normal" forest by 2027.

A larger proportion of the aspen type in Wisconsin--61 percent in 1987--is undermature (40 years old or younger) than in the other two Lake States. Only 7 percent of the area in Wisconsin is overmature (61 years old or older). In Minnesota, 25 percent of the aspen type is more than 61 years old, and only 38 percent is 40 years old and younger. Fifty-four percent of Michigan's aspen type is undermature, and another 25 percent is mature (41 to 60 years old).

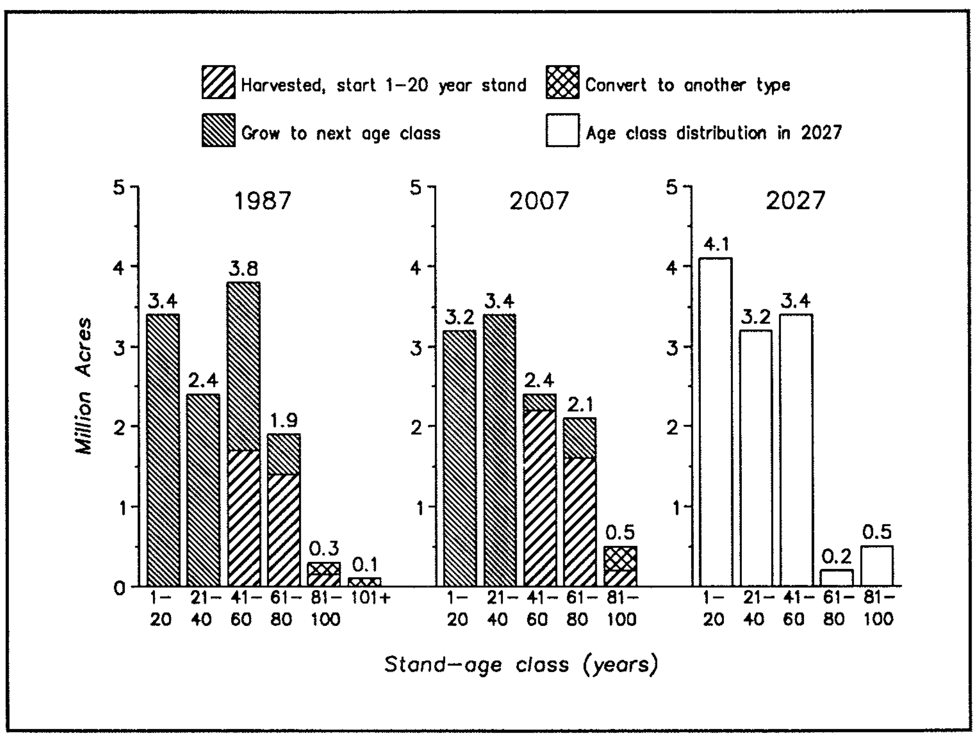

Figure 2.--Area of timberland in the aspen forest type by stand-age class, Lake States, 1987, and hypothetical age class distributions for 2007 and 2027.

About half of the area of the aspen type--48 percent--is owned by farmers and other private parties (Fig. 3). Public agencies administer a nearly equal amount--46 percent. The remaining aspen area (6%) is owned by forest industry. Most of the publicly owned aspen is controlled by state, county and federal agencies other than the USDA Forest Service--34 percent. Twelve percent of the aspen type is on National Forest land.

TIMBER VOLUME

Volumes for 1987 are computer updates of volumes from the most recent inventories of each State prepared for the 1989 Resources Planning Act Assessment (Smith and Hahn 1986, Hahn and Smith 1987, and Smith and Hahn 1989). The Stand and Tree Evaluation and Modeling System (Belcher 1981), a tree growth model developed at the North Central Forest Experiment Station, was used to estimate the change in inventory data. Major components of change are land use change, growth, mortality, regeneration, and removals. Inputs to the model are based on some assumptions and trend analyses, as well as recent remeasurement data from Lake States' permanent sample plots.

Sampling errors are highest for data broken down into the smallest units, such as volume of a single species by 2-inch diameter class. Therefore, we have grouped diameter classes and other data, where possible, to improve the reliability of the information.

In spite of the 10-percent decline in area of timberland in the aspen forest type between the mid-1960s and 1987, the volume of aspen growing stock increased 22 percent during the same period. The 7.1 billion cubic feet of aspen in the mid-1960's grew to 8.7 billion cubic feet by 1987 (Table 3).

The volume gain is due to the maturing of stands that came into being early in this century. The gain is much smaller between the early 1980s and 1987 (average annual change of +0.01 percent). In fact, Minnesota is the only State to show an increase in aspen volume during this period; Michigan and Wisconsin show small declines.

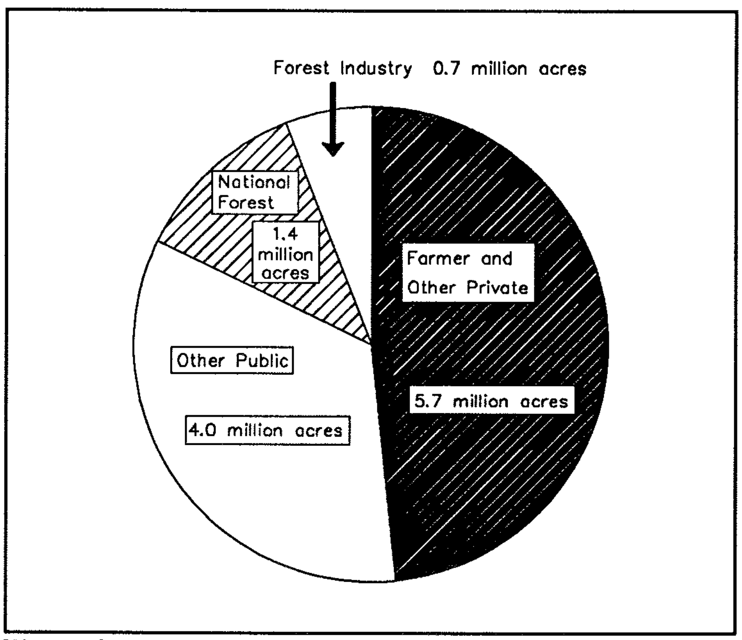

Figure 3.--Area of timberland in the aspen forest type by owner class, Lake States, 1987.

Table 3.--Volume of aspen growing stock on timberland, by State, mid-1960s, early 1980s, and 1987.

State	Mid-1960s	Early 1980s[1]	1987	Average Annual Change Since 1960s
	(In million cubic feet)			
Michigan	2,122.8	2,565.5	2,493.3	+0.83
Minnesota	2,790.8	3,477.8	3,570.8	+1.12
Wisconsin	2,170.8	2,621.6	2,608.3	+1.06
Total	7,084.4	8,664.9	8,672.4	+1.02

[1]Volumes have been adjusted slightly from those published after the most recent inventories to conform to changes in survey definitions and procedures made for the 1987 updates.

Sixty-eight percent of the 1987 aspen growing-stock volume is in the aspen forest type, and another 13 percent is in the maple-birch type. The remainder of the aspen volume is in other forest types (Table 4).

More of the aspen volume is in the aspen forest type in Minnesota (80%) than in Wisconsin (61%) or Michigan (59%). Twenty-three percent of Michigan's aspen volume is in the maple-birch type, compared with 16 percent in Wisconsin and 3 percent in Minnesota. Aspen mixed in small quantities with other species in forest types other than the aspen type is less likely to be harvested, and such stands are unlikely to be converted to the aspen type. Therefore, the 2.8 billion cubic feet of aspen in forest types other than the aspen type probably will not contribute greatly to future aspen supply needs.

Table 4.--Volume of aspen growing stock on timberland by State and forest type, Lake States, 1987.

Forest type	All States	Michigan	Minnesota	Wisconsin
	(In million cubic feet)			
Aspen	5,915.9	1,477.0	2,840.0	1,598.9
Maple-birch	1,116.7	584.8	114.1	417.8
Oak-hickory	441.1	126.3	75.5	239.3
Paper birch	328.3	44.4	162.3	121.6
Other types	870.4	260.8	378.9	230.7
All types	8,672.4	2,493.3	3,570.8	2,608.3

A total of 5.4 billion cubic feet of the 11.2 billion cubic feet of growing-stock trees (of all species) in the aspen forest type is aged 41 to 60 years, considered mature (Fig. 4). Forty is an average rotation age for aspen, although aspen on low sites (site index 50 and less) is harvested at about age 35 if managed for fiber production; and on high sites (site index 70+) it is harvested at about age 60 if managed for sawtimber (Perala 1977). Assuming a rotation age of 40 years and assuming that stands more than 60 years old have started to deteriorate, about 48 percent of the volume in the aspen type is mature and another 24 percent is overmature. The remaining 28 percent is undermature. Obviously there is a need to harvest the oldest stands first and to achieve a more equal distribution of area by age classes as quickly as possible.

In the early 1980s about 50 percent of the volume in the aspen forest type (5.3 billion cubic feet) was mature compared to the 48 percent mentioned above for 1987 (5.4 billion). Only 19 percent of the volume was overmature in the early 1980s (2.0 billion cubic feet), compared to 24 percent of the volume (2.7 billion) in 1987, showing the buildup in older age classes.

Aspen trees do not usually grow to large diameters, although some do exceed 28 inches in diameter at breast height (DBH). Eighty percent of the 1987 aspen growing-stock volume is in trees less than 13.0 inches DBH, and 43 percent is in trees in the 10- and 12-inch diameter classes alone (Table 5). In the early 1980s the respective percents were 84 and 44. In the early 1980s 1.4 billion cubic feet was in larger diameter trees (13.0+ inches), but in 1987 the volume was 1.8 billion, suggesting that stands are generally getting older. Somewhat more volume is in these larger diameters in Michigan (22%) than in Minnesota (21%) or Wisconsin (18%).

In addition to the 8.7 billion cubic feet of aspen growing stock in the Lake States, there is another 0.1 billion in short-log trees (Table 6). These trees contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log. They represent a source of commercially usable wood, the harvest of which would improve the forest.

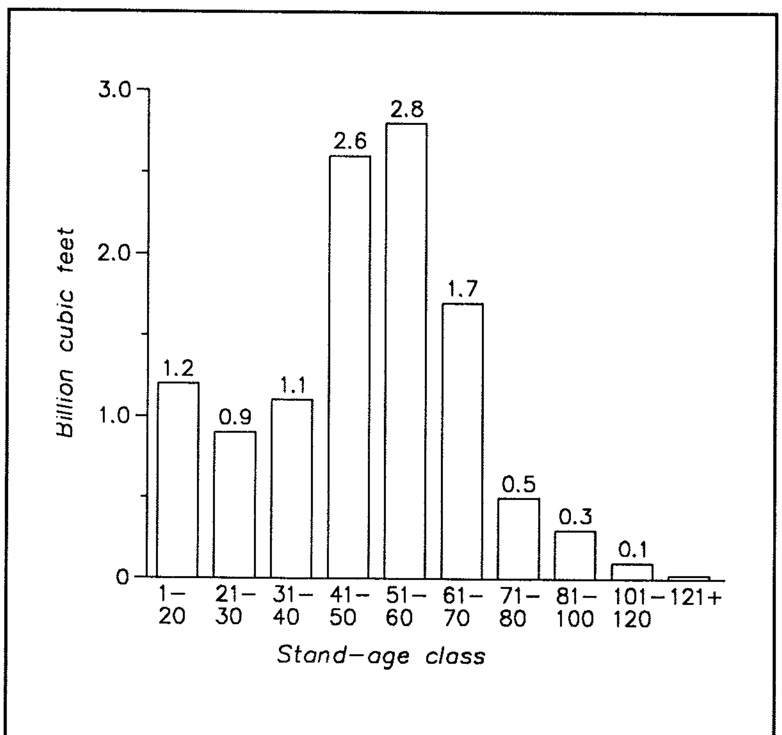

Figure 4.--Volume of growing stock in the aspen forest type by stand-age class and State, Lake States, 1987.

Table 5.--Volume of aspen growing stock on timberland by diameter class and State, 1987.

Diameter Class (inches)	All States	Michigan	Minnesota	Wisconsin
	(In million cubic feet)			
5.0- 8.9	3,140.8	877.1	1,259.7	1,004.0
9.0-12.9	3,763.7	1,072.4	1,550.2	1,141.1
13.0-16.9	1,449.5	432.2	623.7	393.6
17.0-20.9	277.0	91.9	122.8	62.3
21.0-28.9	41.2	19.7	14.4	7.1
29.0+	0.2	--	--	0.2
Total	8,672.4	2,493.3	3,570.8	2,608.3

Table 6.--Volume of short-log aspen trees on timberland by diameter class and State, 1987.

Diameter Class (inches)	Total	Michigan	Minnesota	Wisconsin
	(In million cubic feet)			
5.0- 8.9	--	--	--	--
9.0-12.9	13.1	4.0	5.6	3.5
13.0-16.9	60.4	17.7	33.2	9.5
17.0-20.9	21.2	6.1	12.8	2.3
21.0-28.9	5.1	2.4	2.4	0.3
29.0+	--	--	--	--
Total	99.8	30.2	54.0	15.6

GROWTH AND REMOVALS

The 1987 update information used in this paper included only periodic net growth volumes, rather than net annual volumes for a particular year. Periodic growth for Minnesota, for example, is the total net volume of growth that accrued between 1977, date of the last inventory, and 1987. Because each of the Lake States has a different period between its last inventory and 1987, we divided the periodic growth volumes by the number of years in the period to estimate average annual growth from the early 1980s to 1986. These volumes were adjusted slightly to reflect expected growth rates during the period.

We estimated average timber removals for 1983 to 1986 from Smith and Blyth (1989). That paper reported estimated growing-stock removals from timberland for products (not including "other" removals[2]) by species group for the Lake States, for 1983 to 1987. Removals reported in the early 1980s were total removals, including "other" removals. To make them comparable to early 1980s removals, we adjusted removals for products for 1983 to 1986 by adding an estimate of "other" removals for the period.

Using the above estimates of average annual growth, we found that aspen growth increased from 263 million cubic feet in the early 1980s to 297 million during the period early 1980s to 1986, a gain of 13 percent (Table 7). The annual growth rate in the early 1980s averaged 3.0 percent of inventory compared with 3.4 percent for the period early 1980s to 1986. Aspen growth volume differed by State--in Michigan the average annual change was -0.5 percent, but in Minnesota it was +2.7 percent and in Wisconsin it was +10.4 percent.

Timber removals of aspen increased from 252 million cubic feet in the early 1980s to 333 million during the period 1983-1986, a 32-percent gain. Aspen removals increased in every State, but at differing rates. The average annual increase was greatest in Minnesota (10.4%), followed by Wisconsin (5.5%) and Michigan (2.4%). Removals increased faster in Minnesota because not all of the waferboard mills operating in the State in 1987 were operating in 1977, the date of the last inventory. In the early 1980s total aspen growth exceeded removals by 10 million cubic feet, but by 1983-1986 removals were greater than growth by 36 million cubic feet, reflecting the increased demand. Aspen removals were greater than growth in each of the Lake States in 1987. The disparity between growth and removals was greatest in Minnesota, where the surplus of growth in the early 1980s turned to a deficit in the period early 1980s to 1986, a change of 40 million cubic feet between the two occasions. It may be advisable for aspen removals to be greater than growth for a short period because of the large area of overmature stands with reduced or even negative growth. But if the imbalance continues for an extended period, a substantial inventory decline will occur.

Table 7.--Volume of growth and timber removals of aspen growing stock on timberland, Lake States, early 1980s and early 1980s to 1986.

State	Net annual growth	Ave. annual growth	Timber removals		Difference	
	Early '80s	Early '80s to 1986	Early '80s	Average (1983-1986)	Early '80s	Early '80s-1986
	In million cubic feet					
Michigan	88.5	86.3	83.2	93.0	+5.3	(-)6.7
Minnesota	94.2	114.3	73.0	133.5	+21.2	(-)19.2
Wisconsin	79.9	96.5	96.1	106.7	(-)16.2	(-)10.2
Total	262.6	297.1	252.3	333.2	+10.3	(-)36.1

[2]Growing-stock trees removed but not used for products, or trees left standing but "removed" from the timberland classification by land use change.

Aspen utilization is expected to increase significantly because of company expansions throughout the region, such as the Louisiana Pacific flakeboard mill at Sagola, Michigan, and the recently announced MacMillan Bloedel mill at Deerwood, Minnesota, which will use aspen to produce parallel strand lumber from wafers. With aspen removals greater than growth in all the Lake States, a large sustained expansion in industrial use of the species will probably require a concomitant increase in aspen forest management. Actions that will stretch the supply of aspen in the future include improving the level of stocking of aspen stands; moving toward a more balanced distribution of age classes; and using more of the tops, limbs and stumps of cut trees (not part of growing-stock volume). Planting genetically improved aspen seedlings, as well as thinning and fertilizing aspen stands, are other practices that may move from the experimental to the operational stage in aspen management in the future. Increased use of presently under-utilized species such as paper birch, basswood, and plantation-grown red pine in the manufacture of oriented strand board and waferboard would also help to take the pressure off the aspen resource.

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OPPORTUNITIES FOR ASPEN AND BALSAM POPLAR UTILIZATION IN ALBERTA

B.W. Karaim, E.M. Wengert, and T. Szabo[1]

ABSTRACT.--Until very recently aspen and balsam poplar had been an underutilized resource in Alberta. A very specific and mission oriented R&D program played a major role in turning aspen and balsam poplar from weed species into respected and sought after species for an array of end products. Although we have made great strides there are still many problems and opportunities to address particularly in the area of value added products.

This paper will highlight some of the research projects undertaken with aspen and balsam poplar and commercial developments that have spawned directly and indirectly from this research.

SUMMARY

Alberta aspen and balsam poplar were examined for both their technical and marketing potential. The examination was based on published literature, as well as the authors experiences. A summary of potential uses of aspen and balsam poplar is presented below:

Product	Overall Potential
Pulp & Paper	Aspen can be and has been used for the production of high quality chemimechanical and chemical pulps. The use of aspen pulp is increasing in the manufacture of fine papers and tissue making.
OSB/Maxi-Chip	Both aspen and balsam poplar are being used for the production of waferboard and OSB. The use of ring flaked maxi-chips with electrostatic orientation could increase the profitability of plants using aspen and balsam poplar.
Veneer and Plywood	Although product value is high, manufacturing costs are also very high and market development would be necessary. High quality resource is probably lacking.
Construction Lumber (8/4 Dimension)	Very low product value; very low yields; many unsuccessful industrial trials.

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Utility Lumber (4/4 Dimension)	Moderate to high potential for high quality logs over 24 cm (9-inches) in diameter; profitable residue uses are essential.
Furniture Blanks or Parts	High potential for medium and high quality logs; some market development needed; product value is high.
Children's Furniture	The use of aspen for the production of children's furniture was successfully demonstrated. Based on these results a new project was initiated on a line of juvenile furniture from Alberta aspen.
Shingles	The use of aspen for shingles was demonstrated in Alberta approximately 70 years ago. Interest in the production of aspen shingles is increasing.
Pallet Stock or Parts	High potential, especially with profitable residue use; already active markets in Alberta.
Fuel	Low potential for development of industrial markets; low weight to energy ratio is a problem; coal and natural gas still very cheap in Alberta; briquet manufacturing possible.
Animal Feed & Roughage	Interesting possibility, but still many unanswered questions, including safety of animals and humans; also abundance of other low cost feed in Alberta.
Animal Bedding	High potential for all grades of logs; however, usually a by-product of sawmill; markets must be within 100km (60 miles) of wood processing plant.

Several potential uses are not discussed in this report because of a lack of processing information. These uses include wood flour, wood excelsior or wool, snow fence lath, building logs, and various pressed items from veneer (such as tongue depressors). Manufacturing and marketing opportunities may exist in these areas, as well as other small product and market niches.

Alberta is experiencing a strong surge in forest industry development based on aspen and balsam poplar.

The deciduous resource in Alberta is extensive, and until most recently it had been highly underutilized. Comprised mainly of trembling aspen (Populus tremuloides), Alberta's deciduous forests contain more than 800 million cubic meters of standing timber. The annual allowable cut (AAC) on a sustained yield management basis is 11.4 million m^3.

To put utilization into perspective using this Aspen Symposium as yardstick, back in 1971 less than 2 percent of the hardwood AAC was being used in Alberta. Today if all the recent developments proposed should proceed we would be close to an 80 percent rate of utilization.

Alberta's forest industry currently uses the aspen resource for oriented strandboard, bleached kraft pulp, chemi-thermomechanical pulp (CTMP), pallets, and lumber. Most of these products are either used in Alberta, or exported, in their primary form. Very little secondary processing is currently performed on these aspen products. Aspen lumber, for instance, is typically used in low grade applications (pallets, bins, reels, etc.) which require minimal processing. Very little aspen lumber is currently used in Alberta for furniture, or other high value added applications.

Similarly, very little of the softwood lumber produced in Alberta is processed by the secondary industry into high value-added products.

Aspen has been viewed as a "weed" species in the past, in fact it is still regarded as a weed by many in the primary forest industry. Many technical problems have been cited with excessive decay and dimensional stability heading the list. Considerable research efforts and dollars have been expended by both the Alberta and Canadian governments to solve these inherent problems.

A large part of the R&D effort occurred during the last five years under the Canada/Alberta Forest Resource Development Agreement which recently expired on March 31, 1989. A list of publications is available at the poster session. This list is being constantly updated as more reports are published.

To highlight some of the R&D work that we have done on aspen and balsam poplar I have chosen four product areas to discuss in my presentation. These are: (i) pulp and paper, (ii) OSB/maxi-chip, (iii) children's furniture and (iv) shingles.

Information on other products can be found in the project report by E.M Wengert entitled "Utilization and Marketing Opportunities for Alberta Aspen Solid Wood Products".

PREPARATION OF PULPS FROM SOUND ALBERTA ASPEN AND BALSAM POPLAR BY VARIOUS PROCESSES

SUMMARY

Sound Alberta aspen and balsam poplar have been subjected to a range of processes to produce the following pulps: i) bleached kraft, ii) bleached alkaline sulphite/anthraquinone, iii) high yield sulphite, iv) neutral sulphite semi chemical, v) bleached solvent (methanol), and vi) chemi-thermomechanical. The pulps have been evaluated for yield and strength characteristics. Results indicate that sound samples of the two species produced good quality pulps for the processes studied (Arbokem 1987, Econotech Services 1987, VPI 1988).

OBJECTIVES

The studies were designed to identify: a) typical fibre characteristics, including fibre length, cell wall thickness, coarseness and wood density; b) key aspects of the pulping processes used and responses of aspen and balsam poplar to them in terms of yield; c) ease of pulping relative to chemical requirement, reject material and quality of unbleached pulp; d) key aspects of bleaching processes required for the pulp; e) quality of the bleached pulps with emphasis on end-use potential.

WOOD CHARACTERISTICS

The logs were debarked and chipped. The William's Classification of chips produced the data in Table 1.

The data indicate no major difference in chipping characteristics. Aspen however, yielded slightly larger chips than the balsam poplar.

The basic wood characteristics of aspen and balsam poplar are compared to eucalyptus in Table 2.

Aspen and balsam poplar have a lower density than eucalyptus but are equal or better than eucalyptus in terms of brightness.

Table 1.--William's round hole classification of chips.

Size	Aspen	Balsam Poplar
+1 1/8"	4.9	6.4
+ 7/8"	27.3	21.9
+ 5/8"	41.7	36.0
+ 3/8"	20.4	26.4
+ 3/16"	4.6	7.8
- 3/16"	1.1	1.5

Table 2.--Basic characteristics of aspen, balsam poplar and eucalyptus.

Characteristic	Aspen	Balsam Poplar	Plantation Eucalyptus
Basic wood density, g/ml	0.348	0.334	0.405
Average fibre length, mm	0.84	0.90	1.11
Cell wall thickness, u	4.0	4.1	1.6
Coarseness, mg/100m	10.1	12.0	--
Wood brightness T525	62.6	54.1	54

BLEACHED KRAFT

Kraft pulping conditions and results are described in Table 3.

The basic properties of the bleached kraft pulp for aspen, balsam poplar and eucalyptus at two freeness levels are given in Table 4.

BLEACHED ALKALINE SULPHITE/ANTHRAQUINONE (ASAQ)

Pulping conditions and results are described in Table 5. The ASAQ process provides a low odor, high yield system producing a pulp with good strength characteristics. Table 5 confirms the superior unbleached yield over the kraft process. Table 6 shows that the pulp bleached easily to very high brightness.

Table 3.--Kraft pulping conditions and results.

	Aspen	Balsam Poplar	Plantation Eucalyptus
Cook number	B1297	B1298	--
Active alkaline (AA), % on o.d. wood	15.0	15.0	12
Sulphidity, %	30.7	30.1	25
Liquid to weight ratio (L/W)	4/1	4/1	3.5/1
Maximum temperature, °C	160	160	170
Time to maximum, minutes	60	60	77
Time at maximum, minutes	70	70	70
Total yield, %	58.2	57.1	54.2
Knots, %	0.8	0.5	0.4
Total rejects, %	4.0	1.7	1.4
Kappa No. 40 ml	9.5	10.3	11.0
Viscosity, 0.5% CED, cp	90.0[1]	78.2[1]	80.4
Residual extracted alkaline (EA), g/L Na_2O	8.07	7.75	1.7
Residual active alkaline (AA), g/L Na_2O	10.8	10.9	3.6

[1]Partially insoluble

Table 4.--Comparison of bleached kraft aspen, balsam poplar and eucalyptus pulps at 500 and 300 CSF (PFI Data).

Properties	Aspen	Balsam Poplar	Plantation Eucalyptus
500 mLs CSF			
PFI, revs	40	310	50
Burst index, kPa.m²/g	2.80	3.23	3.20
Tear index, mN.m²/g	7.4	8.8	12.4
Tensile index, N.m/g	45	50	54
Density, kg/m³	680	670	645
Porosity, sec/100ml	9	11	5
Opacity, %	74	74	78
Fold, log	1.2	1.4	--
300 mLs CSF			
PFI, revs	2110	2720	2400
Burst index, kPa.m²/g	6.25	7.40	7.54
Tear index, mN.m²/g	8.4	11.6	11.6
Tensile index, N.m/g	94	102	111
Density, kg/m³	800	890	761
Porosity, sec/100ml	166	100	53
Opacity, %	67	63	72
Fold, log	2.3	3.5	--
Bleaching (D/C EoD)			
Total yield, %	95.4	94.4	--
Brightness, Elrepho	91.1	91.7	--
Viscosity, 0.5% CED, cp	54.2	45.7	--

Table 5.--Alkaline sulphite/anthraquinone (ASAQ) pulping conditions and results.

Furnish	Aspen	Balsam Poplar
Cook Number	L76-1	L76-3
Chemical Charge:		
Total Na_20, %	19.29	19.29
Na_2S0_3, % of total as Na_20	74.65	74.65
Na_2C0_3, % of total as Na_20	15.97	15.97
Na0H, % of total as Na_20	9.38	9.38
THAQ, % on o.d. wood	0.1	0.1
L/W	5/1	5/1
Maximum temperature, °C	165	165
Time at maximum, minutes	240	240
Total yield, %	60.9	57.5
Kappa No. 40 ml	12.5	12.2
Total rejects, %	0.7	2.6
Initial pH of liquor	13.19	13.26
pH of spent liquor	9.06	9.28
Pulp viscosity, 0.5% CED, cp	105.7	123.3

Note - Other conditions were:

Presteaming for 3 minutes at atmospheric pressure
25 minutes from 90°C to 130°C
45 minutes at 130°C
30 minutes from 130°C to 168°C
Cooked chips hot refined at 0.050" and then at 0.020"
Pulps screened through 12 cut flat screen.

Table 6.--Comparison of kraft and ASAQ pulp strengths for aspen and balsam poplar at 500 and 300 CSF (PFI Data).

Properties	------- Kraft -------		------- ASAQ -------	
	Aspen	Balsam Poplar	Aspen	Balsam Poplar
500 mLs CSF				
PFI, revs	40	310	0	140
Burst index, $kPa.m^2/g$	2.80	3.23	3.26	3.20
Tear index, $mN.m^2/g$	7.4	8.8	7.8	9.5
Tensile index, N.m/g	45	50	52	52
Density, kg/m^3	680	670	699	690
Porosity, sec/100ml	9	11	13	14
Opacity, %	74	74	72	74
Fold, log	1.2	1.4	1.4	1.3
300 mLs CSF				
PFI, revs	2110	2720	1120	2400
Burst index, $kPa.m^2/g$	6.25	7.40	5.42	7.32
Tear index, $mN.m^2/g$	8.4	11.6	7.5	8.3
Tensile index, N.m/g	94	102	86	90
Density, kg/m^3	800	890	780	810
Porosity, sec/100ml	166	100	130	187
Opacity, %	67	63	66	66
Fold, log	2.3	3.5	2.9	3.9
Bleaching (D/C EoD)				
Total yield, %	--	--	91.6	91.6
Brightness, Elrepho	--	--	92.2	91.7
Viscosity, 0.5% CED, cp	--	--	74.1	89.2

BLEACHED SOLVENT (METHANOL) PULP

The use of a methanol based process for aspen and balsam poplar offers potential advantages for Alberta relative to the chemical used and the possible use of lignin and carbohydrate by-products.

Pulp conditions and results are described in Table 7. The two species provided very high unbleached yields as expected for the high kappas. Some of this high yield is lost in bleaching therefore the end result is a similar overall yield to that of kraft.

Short sequence bleaching (Table 8) was not as effective as in the case of kraft and ASAQ, but still provided 90 brightness pulp.

Table 7.--Solvent pulping (methanol) conditions and results.

Furnish	Aspen	Balsam Poplar
Cook Number	DSS #1	DSS #2
Weight of chips, o.d. g	400	400
Cooking liquor:		
Methanol, 1	6.40	6.40
Water, 1	1.21	1.08
$MgSO_4$, g.7 H_2O	98.0	98.0
L/W	20/1	20/1
Maximum temperature, °C	190	190
Total cooking time, (hrs:min)	3:00	3:00
Initial pH	4.90	5.0
End pH	4.64	4.84
Total yield, %	63.8	66.3
Kappa number	39.7	54.0
Viscosity, 0/5% CED, cp	42.6[1]	29.0[1]

[1]Partially insoluble.

Note:

Chips were defibred using a Lightning mixer
Sprout-Waldron refined at 0.015"
Screened through 0.010" cut flat screen

Table 8.--Comparison of kraft and solvent pulp strengths for aspen and balsam poplar at 500 and 300 CSF (PFI Data).

Properties	----Kraft---- Aspen	Balsam Poplar	----Solvent---- Aspen	Balsam Poplar
500 mLs CSF				
PFI, revs	40	310	120	70
Burst index, kPa.m^2/g	2.80	3.23	3.20	3.40
Tear index, mN.m^2/g	7.4	8.8	6.6	7.7
Tensile index, N.m/g	45	50	53	52
Density, kg/m^3	680	670	700	700
Porosity, sec/100ml	9	11	16	18
Opacity, %	74	74	73	72
Fold, log	1.2	1.4	1.4	1.3
300 mLs CSF				
PFI, revs	2110	2720	1250	1530
Burst index, kPa.m^2/g	6.25	7.40	5.31	6.07
Tear index, mN.m^2/g	8.4	11.6	6.9	7.5
Tensile index, N.m/g	94	102	87	91
Density, kg/3	800	890	800	800
Porosity, sec/100ml	166	100	130	164
Opacity, %	67	63	67	64
Fold, log	2.3	3.5	1.7	2.5
Bleaching (D/C EoD):				
Total yield, %	--	--	87.4	83.3
Brightness, Elrepho	--	--	89.8	89.7
Viscosity, 0.5% CED, cp	--	--	63.4	62.3

NEUTRAL SULPHITE SEMI-CHEMICAL (NSSC) PULPS

Hardwoods are frequently used as the base for corrugating medium prepared by using the NSSC process.

Pulping conditions and results are described in Table 9.

The results in Table 10 show that the aspen and balsam poplar yield equivalent or superior strength relative to the more important burst and concora, compared with south eastern USA hardwoods.

Trembling aspen and balsam poplar would be suitable raw materials for producing corrugating medium.

Table 9.--NSSC pulping conditions and results.

Furnish	Aspen	Balsam Poplar
Cook number	L75-1	L75-3
Chemical Charge:		
Na_2SO_3, % as Na_2SO_3	12.0	12.0
Na_2CO_3, % as Na_2CO_3	5.0	5.0
L/W	5/1	5/1
Maximum temperature, °C	168	168
Time at maximum, minutes	90	90
Total yield, %	77.3	77.1
Total rejects, %	0.9	2.8
Initial pH of liquor	11.66	11.63
pH of spent liquor	6.85	7.22
Pulp viscosity, 0.5% CED, cp	105.7	123.3

Note - Other conditions were:

Presteaming for 3 minutes at atmospheric pressure
25 minutes from 90°C to 130°C
45 minutes at 130°C
30 minutes from 130°C to 168°C
Cooked chips hot refined at 0.050" and then at 0.020"
Pulps screened through 12 cut flat screen

Table 10.--Comparison of NSSC aspen and balsam poplar pulps with NSSC pulp from south eastern USA hardwoods at 400 CSF (PFI Data).

Analyses	Aspen	Balsam Poplar	Hardwood
Burst index, kPa.m²/g	3.28	4.02	2.75
Tear index, mN.n²/g	6.8	6.7	8.0
Tensile index, N.m/g	67	77	67
Density, kg/m³	630	670	476
Concora, N	351	418	364

HIGH YIELD SULPHITE

A high yield sulphite pulp with its attendant high brightness could be used in newsprint.

Pulping conditions and results with this process are described in Table 11. The unbleached pulp is of high yield and brightness. The pulps were readily bleached by a mild peroxide treatment to the brightness level required in newsprint (see Table 12).

Table 11.--High yield sulphite pulping conditions and results.

Furnish	Aspen	Balsam Poplar
Cook Number	A1934	A1935
Chemical Charge:		
SO_2 to give 4.5 pH		
NaOH, % on o.d. wood	6.2	6.2
L/W	5/1	5/1
Maximum temperature, °C	155	155
Time to max temp, min	120	120
Time at max temp, min	90	90
Total yield, %	66.0	75.5
Total rejects, %	0.8	5.3
Initial pH of liquor	4.5	4.5
pH of spent liquor	3.2	3.9
Kappa number	57.5	85.7
Brightness, Elrepho	52.4	50.6

Note - Other conditions were:

Presteaming: 10 minutes at atm pressure, 100°C
Cooked chips refined at 0.050" S/W and then at 0.020" S/W
Cooking liquor: pH adjusted to 4.5 with SO_2

Table 12.--Bleaching of high yield sulphite to brightness for newsprint.

Furnish	Aspen	Balsam Poplar
Cook Number	A1934	A1935
H_2O_2 on pulp, %	1	1
Time, minutes	90	90
Temperature, °C	60	60
Initial pH	10.95	10.91
Final pH	8.00	8.19
Initial brightness, TAPPI, Elrepho	52.4	50.6
Final brightness, TAPPI, Elrepho	62.2	58.6

Note - Other conditions were:

0.05% epsom salts
2.0% silicate
0.5% DTPA
1.23% total alkali as NaOH

CHEMI-THERMOMECHANICAL PULP (CTMP)

The pulp production information is described in Table 13 and the refining and bleaching information is described in Table 14. The pulp properties of the bleached handsheet are provided in Table 15.

The comparison of key properties of aspen and balsam poplar with those of the eucalyptus is provided in Table 16.

Table 13.--CTMP production data.

Furnish (-7/8 +3/16)	R261 Aspen			R263 Balsam Poplar		
Wood brightness	62.6			54.1		
Pretreatment:						
Chip wash, hot distilled H_20 75-80°C, min	5			5		
Presteam, pressurized, psig	51-52			51-52		
Time, min	15			15		
Impregnation, atmospheric:						
Chemical application, Na0H, %	5			5		
Na_2S0_3%	2			2		
pH, as found	13.61			13.64		
Time, min	35			35		
Temperature, °C, initial	49			45		
final	70			68		
Compression:						
Time, min:sec	1:28			1:22		
Pressing force, tons	30			40		
O.D. content, %	41.6			45.0		
Retention Period:						
Tim, min	25			25		
Temperature, °C, initial	55			56		
final	49			48		
Refining data:						
First pass yield, %	94.1			94.5		
Refiner pass number	2	3	3	2	3	4
C.S. freeness, mLs	259	180	92	285	220	120

Table 14.--Bleaching data.

Species	----Trembling Aspen----			----Balsam Poplar----		
Freeness	240	161	79	260	200	101
Bleaching, 4% H_2O_2						
Total alkali, %	3.3	3.3	3.3	2.9	2.9	2.9
Final pH	9.8	9.7	9.8	10.0	10.0	10.1
Residual, % of applied	47.8	45.9	44.4	39.0	37.2	37.2
Consumption, %	2.09	2.16	2.23	2.44	2.51	2.51
Ion contaminants before pretreatment with 0.5% DTPA at pH 7						
Mn, ppm	4.1	4.7	4.4	11	10	11
Cu, ppm	7.2	19	20	15	12	26
Fe, ppm	56	83	71	83	84	96
Ion contaminants after pretreatment						
Mn, ppm	1.4	1.3	1.3	5.5	5	4.4
Cu, ppm	5.9	11	9.2	14	8.4	12
Fe, ppm	58	75	72	87	79	92
Brightness, T525, %						
Initial	46.0	45.5	45.7	39.0	41.3	37.8
Final	68.3	68.0	66.6	62.8	63.4	61.5
Change	22.3	22.5	20.9	23.3	22.1	23.7

Note - Standard conditions for bleaching:

Time, hours	4
Consistency, %	10
Temperature, °C	60
$MgSO_4$, %	0.05
Sodium silicate, %	3.5

Table 15.--Bleached handsheet properties.

Handsheet Properties	----Trembling Aspen----			----Balsam Poplar----		
C.S. freeness, mLs	240	161	79	260	200	101
Drainage, sec	7.7	12.7	27.9	6.6	8.9	15.8
Density, $kg.m^3$	563	585	645	505	538	583
Bulk, cc/g	1.78	1.71	1.55	1.98	1.86	1.72
Burst factor	27	30	37	20	22	27
Burst index, $kPa.m^2/g$	2.65	2.96	3.61	2.01	2.15	2.62
Tear factor	72	70	67	72	70	69
Tear index, $mN.m^2/g$	7.08	6.87	6.61	7.03	6.85	6.77
Tensile, m	5562	6115	7557	4565	4992	5816
Tensile index, N.m/g	55.6	60.0	74.1	44.8	49.0	57.0
Opacity, T519, %	79.6	80.3	79.8	85.9	87.0	87.5
Scattering coeff, m^2/kg	33.8	34.4	32.1	40.8	42.0	43.0
Absorption coeff, m^2/kg	0.71	0.77	0.76	1.20	1.26	1.29
Porosity, Gurley, sec/100ml	396	1015	3676	100	201	773
Pulp Properties:						
Pulmac rejects, %						
0.006"	0.41	0.20	0.02	0.18	0.04	0.01
0.004"	9.6	6.0	2.2	8.6	5.0	1.42

Table 16.--Comparative data for bleached CTMP[1].

	Aspen	Balsam Poplar	Eucalyptus Globulus	Eucalyptus Saligna
C.S. freeness, mLs	79	101	86	102
Density, kg/m^3	645	583	522	445
Tear index, $mN.m^2/g$	6.6	6.8	6.1	5.0
Tensile index, N.m/g	74.1	57.0	50.7	41.2
Opacity, T519, %	79.8	87.5	79.5	85.0
Scattering coeff, m^2/kg	32.1	43.0	42	47
Brightness, %				
Initial	37.8	45.7	53.6	42.6
Bleached	61.5[2]	66.6[2]	81.1	77.1
Gain	23.7	20.9	27.5	34.5

[1]Conditions for pretreatment, refining and bleaching are the same for all pulps with the exception of H_2O_2 applied for eucalyptus, which was 4.5%.

[2]Pulping was designed to give high strength. A brightness of 80 can be achieved at higher yield/lower strength.

CONCLUSIONS

1. Balsam poplar produced higher strength paper products than aspen, but slightly lower pulping yields.

2. Compared to softwoods the two poplars produced higher pulping yields and had lower K numbers entering the bleach plant which would reduce the environmental impact. In general, chemical requirements for the hardwoods were lower than for softwoods.

3. Compared to eucalyptus, aspen and balsam poplar produced higher yield kraft pulp but somewhat lower strength. These kraft pulps bleached very readily by the short sequence D/C EoD which represents a significant capital advantage over softwoods. The balsam poplar kraft pulp was significantly higher in strength than that from aspen.

4. Alkaline sulphite/anthraquinone (ASAQ) pulping produced higher unbleached yields than kraft but lower yields following bleaching. Overall yield was similar to kraft. The pulp bleached very readily to a high brightness and was stronger than kraft at the higher freeness levels.

5. Solvent pulping using methanol provided similar overall yields as kraft and also bleached to 90 brightness with short sequence bleaching. At the higher freeness levels, strengths were superior to kraft except for tearing.

6. Trembling aspen and balsam poplar would make satisfactory corrugating medium using the NSSC process.

7. High yield sulphite pulping produced pulps with good yield and brightness. With a mild peroxide treatment newsprint brightness was achieved.

8. Chemi-thermomechanical pulping (CTMP) of aspen and balsam poplar confirmed the potential of this process which is well documented in the literature.

RING FLAKED MAXI-CHIPS: THE MANUFACTURE, TESTING AND EVALUATION OF COMPOSITE BOARD MADE FROM ALBERTA WOODS

The wood species used in the study are those abundant in the Province of Alberta namely: aspen, balsam poplar and spruce/pine. The spruce/pine would come from sawmill residuals, whereas the aspen and balsam poplar would be utilized as round wood. In order to maximize utilization and minimize costs, the plant must display economies of scale and manufacture a panel that is structurally efficient and marketable as an effective substitute for plywood and waferboard in major end-use applications. This work discusses a method by which significant quantities of Alberta wood species can be used in a technically and economically viable manner (Morrison-Knudsen 1987, VPI 1988)

The oriented three-layer panel (OSB) would be used in load bearing applications such as roofing and flooring. The top and bottom face layers would consist of in-line oriented flakes while the core would have cross-oriented flakes.

If the wood raw material is in the form of a maxi-chip produced from sawmill, plywood mill residues or roundwood, ring flakers may be used to convert chips into flakes and FORCELINE orientation used to manufacture panels. This approach can provide lower capital requirements and a higher return on investment compared to a structural panel plant utilizing whole log flaking.

OBJECTIVES

The objectives of the oriented three-layer panel study were as follows:

1. Determine size classification of chips used for this study.

2. Establish panel modulus of elasticity and linear expansion properties on a separate face and core layer basis.

3. Based on engineering calculations appropriate to sandwich panels, determine estimations of modulus of elasticity parallel to the major axis and cross panel linear expansion for 7/16 and 1/2-inch panels. Compare these properties to the American Plywood Association (APA) requirements for uniform load and oven dry vacuum pressure soak linear expansion.

4. Manufacture five oriented 7/16-inch three-layer panels at 38 lb. per cubic foot (PCF) density for evaluation.

Information on the procedure, chip and flake geometry and screen analyses, single layer panel actual results, three layer panel estimations, and three layer panel actual results can be obtained from the study reports (Morrison-Knudsen 1987, VPI 1988).

CONCLUSIONS

1. This study demonstrates that a structurally efficient panel made with ring-cut maxi-chips and FORCELINE orientation can be designed to equal or exceed the flexural stiffness and linear expansion performance of many OSB panels now on the market.

2. These oriented panels, from a variety of wood species, can be designed to meet American Plywood Association requirements for uniform loading and cross panel linear expansion. The designer must efficiently arrange various factors such as densities, chip forms, classification of face and core flakes, resin/content, face/core ratios and thickness in order to meet performance standards. Market strategy and economics will further define objectives.

3. Oriented single layer panels made from each species or admixtures of species investigated produce high MOE's, high panel stiffness, and low linear expansions. Balsam poplar panels exhibited the highest orientation index while aspen produced the highest modulus of elasticity and lowest linear expansion.

4. Of considerable importance to the economies of the process is the fact that FORCELINE orientation effectively utilizes 96 percent to 98 percent of the ring flaked wood.

5. The Canadian wood industry has had difficulty in flaking balsam poplar. Initial trials of ring flaking balsam poplar indicated that the wet flakes folded over the knife cutting edge and plugged the slot between the knife and pressure lip. Drying the wood below the fiber saturation point (25 to 35 percent moisture content, ODW) eliminated the problem and produced an acceptable flake for FORCELINE orientation.

6. Three layer panel estimations revealed at 41 PCF densities, 7/16-inch and 1/2-inch oriented panels should easily pass the APA 24/16 and 32/16 roof/floor uniform load span ratings, respectively. Oven-dry vacuum pressure soak linear expansion should be less than the 0.5 percent requirement for the APA and the 0.4 percent requirement for CAN3-0437. The panel can be satisfactorily made with 100 percent of each species or various admixtures of the three species.

7. High flake length/thickness ratios yield high panel bending properties. High flake length/width ratios improve orientation efficiencies. To increase the flake length/width ratios, all face flakes were tumbled in a rotary-tumble drum blender. Without this processing step, MOE orientation ratios would be below 4/1 and panel MOE would have been below the requirement for 24/16 and 32/16 roof/floor span rating.

USE OF ALBERTA ASPEN FOR THE MANUFACTURE OF CHILDREN'S FURNITURE

The objectives of this study were: (i) to determine the optimal methods for drying, machining, fastening, gluing and finishing aspen for use in furniture manufacturing, and (ii) to design, construct and market a complete line of solid wood children's furniture made completely from Alberta aspen (H.P.C. Construction 1987, VPI 1988) which has the characteristics given in Table 17.

The line of children's furniture which was developed has the following components:

1. Crib
2. Change table
3. Change commode
4. High chair
5. Toy box

The crib has been designed for a maximum useful service life. It can be converted to a junior bed, or a junior sofa by merely inserting the optional solid wood sides. Similarly, the change table attached to the top of the commode can provide alternate uses. After the child graduates from diapers, the commode can be used by itself as an attractive dresser. The high chair, likewise, converts to a child's play set of table and chair.

Table 17.--Characteristics of Alberta Aspen.

Feature	Characterization
Gluing	Excellent gluing properties. Weldwood "Prestoset" or Lepages Sure Grip gave equal performance. No staining problems.
Sanding	New belts required; must have SHARP belt to prevent fuzzy finish. No major difficulties.
Finishing	Both hot and cold spray lacquer tested and performed well. Sealer coat (thinned) is required before application of two top coats.
Drying	Six months to dry from 46 percent MC to 6 percent. Indoor, air drying resulted in a 6 percent downfall. Some end checks. No serious problems.
Machining	Very sharp knives are required for planing and cutting. Dull knives result in "fuzzy" edges. When crosscutting, ordinary steel saw blade better than carbide tipped. No serious problems.
Fastening	Very good for stapling. Can staple right at ends of boards. Good screw holding.

The current project has proved, beyond a doubt, that Alberta aspen is suitable for use in high quality furniture manufacturing. No major difficulties were experienced in using Alberta aspen in high quality children's furniture. Technically, all three woods performed well. From a marketing perspective, we have enjoyed good success to date with all three species. The consumer acceptance of aspen, pine and spruce has been excellent. This project has helped change the image of aspen as a weed tree, and has stimulated interest in Alberta hardwoods and softwoods alike as feedstocks for high quality, high value added, high employment secondary wood products manufacturing.

In conclusion, it is clear that the manufacture of children's furniture in Alberta, using Alberta aspen, is a viable business opportunity. Aspen was proven technically suitable for the manufacture of children's furniture. Provided that the lumber is graded and dried properly, we experienced no unusual problems with aspen, in machining, fastening, gluing, sanding and finishing. Contrary to some opinions, we found all three wood species to be well suited technically for furniture manufacture.

Likewise, consumer reaction to the Alberta product has been exceptional. Aspen was well received by consumers. Initial sales have been encouraging. Both domestic and export (outside of Alberta) opportunities appear to be abundant. Our proximity to the wood resource, and to the market (most of the competition is in eastern North America, or in Europe), are advantages to exploit. Furthermore, children's furniture manufacture could serve as a springboard into other production line furniture manufacturing.

While the manufacture of children's furniture from Alberta aspen is a promising growth opportunity, there are problems impeding the development of this industry. We feel that the Alberta government could assist the development of the furniture industry in this province by: 1) Encouraging the selection of high quality "clears" from standard dimension mills; 2) Continuing to educate the primary and secondary industry regarding topics such as custom lumber drying, hardwood grading, etc.; 3) Assisting the secondary industry in marketing and capital expansion.

ASPEN SHINGLES AND SHAKES IN ALBERTA

SUMMARY

The production of shingles and shakes from aspen has been demonstrated at a number of places. The results of this study support the technical feasibility and conclusion that a viable shingle/shake operation could be set up around the Lac La Biche area provided the market economics were favorable. Prior to establishing a mill for the production of aspen shakes and shingles, it is recommended that a detailed business plan be developed. Details for consideration of such a document are provided (Foal Enterprises 1987, Silvacom 1988).

INTRODUCTION

Aspen roof coverings were used successfully in the northeastern part of Alberta on farm buildings and rural housing. In these applications aspen has demonstrated over 20 years of satisfactory service performance. Aspen shingles and shakes are also manufactured in Arizona, New Mexico and Colorado in the United States.

The objective of this study was to determine whether an aspen shingle and shake manufacturing facility could be developed based on the resource quality that exists around the Lac La Biche area in Alberta.

APPROACH I

Test blocks ten inches in diameter by eighteen inches long were sawn on a machine identical to the one installed by Aspen Mills at McRae. It was a good comparison as the mill was cutting 18" tapersawn shakes using cedar. Also, the sawyer was an experienced shingle sawyer.

The total recovery of shakes 5/8" thick by 18" long from one 10" round block was 66 lineal inches (shakes set side by side). When applied to a roof, or wall, at the standard 7 1/2" exposure they would cover 3.44 square feet of roof area.

To produce one square of shakes it would require thirty blocks 10" in diameter, or 45 lineal feet of logs. This amounts to 0.76 cubic meters of logs of good quality. Based on the available cost of logs to the mill we have estimated that the wood cost would amount to $21.50 per square.

The following widths of shakes were cut from the test blocks and covered all grades:

8" wide shakes - 19.3%
7 3/4" wide shakes - 18.7%
7 1/4" wide shakes - 4.3%
6 3/4" wide shakes - 12.3%
6 1/2" wide shakes - 3.9%
6" wide shakes - 10.9%
5 1/2" wide shakes - 10%
5" wide shakes - 9%
4 1/2" wide shakes - 2.7%
4" wide shakes - 2.4%
3 1/2" wide shakes - 4.2%
3 1/4" wide shakes - 1.9%

Average shake width was 6.11".

The grading of the shakes produced a low recovery particularly for roofing applications. It was somewhat better for wall applications. The recovery figures were as follows:

Roof shakes - 28%
Sidewall shakes - 56%
Decorator and rejects - 15%

Using the standard West Coast shingle machine that cuts 33 cedar clips (shingles) per minute for aspen, would require slowing it down to 26 clips per minute to get a smoother cut, as aspen tends to choke the gullets of the shingle machine.

Actual shingles produced per minute with aspen would amount to 19 clips with good wood and a fast operator. This also takes into account the production time lost when the blocks are being placed into the machine. The 19 clips is considered an average over a given period of time.

This pertains to the following:

19 clips with an average width of 6.11" equals 116 lineal inches of shakes per minute. Per hour 116 lineal inches times 60 minutes = 6,960 lineal inches of shakes. One square of shakes contains 1,920 lineal inches of shakes. When this is carried to a per hour output the equation is 6,960 lineal inches of wood divided by 1,920 inches of wood which equals 3.62 squares. This equals twenty-seven squares per 7 1/2 hour shift. However, twenty-three to twenty-four squares per shift would be more realistic.

Taper-sawn shakes were suggested because physically there are 700 lineal inches less wood to cut as opposed to shingles and a labour handling cost saving of 27 percent. The actual cut out per square between shingles and taper-sawn shakes is the same.

If shingles were considered, the daily production of shingles would be 2.6 squares/hour in a 7 1/2 hour shift/day, which equals 19.5 squares per day.

On the West Coast daily production is about 35 squares and is about 80 percent No. 1 Grade.

Western Red Cedar lends itself well to cutting shingles or tapersawn shakes in an upright shingle machine, as it cuts very smooth. However, aspen tends to be fuzzy on one face of the shake. By passing the shakes through a groover this will eliminate the fuzzy appearance and also give the shakes a split like texture which will improve the aesthetics and also dramatically improve the performance of the shakes as the grooves will tend to channel the water straight down to the butt of the shake. It should be noted that when shingles or shakes are cut on a circular type saw, the tendency is for the water to follow saw marks to the edge of the shake.

Cross grain on an upright shingle machine also can become a problem. Cross grain in shingles and shakes is defined as follows: A pattern in which the fiber or longitudinal elements deviate from a line parallel to the (face) side of the piece. In shingles it is the angle of grain extending from the face to the back.

Total cost of required equipment would be around $50,000.

APPROACH II

It is our suggestion that another procedure be used to manufacture high quality shakes with the least requirement of skilled labour.

In considering a viable shake operation, two species - lodgepole pine and tamarack should be considered as they are both excellent species for wood roofing and sidewall material.

The concept that we are proposing here is considerably different from the standard approach to the manufacture of shingles and shakes, however when related to cost of equipment, wood supply, and labour requirements amortized over the increased daily production, we feel that it is worth considering.

We envision the following production facility:

1. Logs are harvested and brought to the mill. Length of logs to be determined by:

   (a) Multiples of end products.
   (b) The ideal log length to harvest.

2. At the mill the logs are cut into the desired lengths, depending on the end product.

3. The Mighty-Mite concept of the log lying on a bed and the saws horizontally cutting a board at each pass is ideally suited to this concept, as the waste produced by tree squaring will be eliminated.

   The equipment required here can be especially designed so that as the saws pass through each board, it will not only be cut for thickness, but will also be edge-trimmed by the moveable saws giving the maximum yield for each board down to a fraction of an inch. This is a two man operation.

4. At this point full length boards that will not make shakes can be pulled and sold for other end uses.

   Boards that have defects in them that cannot be used for shakes will have to be evaluated to determine if the defects can be cut out for maximum recovery, or whether the boards should be pulled.

5. Boards are then passed through a trim saw that will cut them to the desired length. Also, at this point, if a large knot or other defect occurs in an otherwise good board these defects can be cut out.

6. The short boards, or blanks as they are called, then pass through a band saw and produce two uniform shakes. With an automatic feed no operator is required.

7. The taper-sawn shakes are then passed through a groover that will give one face a textured split-like look. The finished product is then bundled and ready for shipment.

Recovery

From one thousand board feet of sawn lumber, one inch thick, the following can be obtained:

1. 3/4" butt - 1/8" tip x 18" Long

   - 1,000 square feet of boards, 1 inch thick.
   - 1,333 pieces with an average width of 6 inches.
   - 16,000 lineal inches of finished shakes (laid side by side).
   - 33 bundles of shakes, each containing 480 lineal inches of wood, or 8.3 squares. Four bundles per square, a square represents enough shakes to cover 100 square feet of roofed area at a 7 1/2" exposure.

2. 3/4" butt - 1/8" tip x 24" Long

   - 1,000 square feet of boards 1" thick.
   - 1,000 pieces with an average width of 6".
   - 12,000 lineal inches of finished shakes.
   - 41.66 bundles each containing 288 lineal inches of wood, or 8.3 squares. Five bundles per square, a square represents enough shakes to cover 100 square feet of roofed area at a 10" exposure.

Thirty-five (35) cubic meters of good logs will produce approximately 21 cubic meters of lumber using a 60 percent recovery factor. This amounts to 8904 board feet of lumber, 1" thick. Cost of lumber will have to be determined from log costs.

The total cost of required equipment would be around $70,000.

CONCLUSIONS AND RECOMMENDATIONS

To obtain a production rate of 60 squares per day, which is the capacity of the resaw, it would require a supply of 7,500 to 8,000 board feet to the resaw. The key points here are:

1. Greater end production.

2. The finished boards can be graded prior to being cut into short boards or blanks and entering the resaw.

   Low grade boards can be culled for other end uses or can be trimmed prior to resawing. It must be noted that regardless of the quality of the board that goes through to produce the end shake, it still requires feeding time and is a negative cost.

3. One inch boards can either be supplied by other producers or other equipment, and be brought in to offset any shortage of material produced within the mill.

This type of operation also has some other side benefits in that in a period of low demand for the end product, the mill can operate one day cutting the required number of boards to feed the mill and the following day run them through to produce shakes. This would essentially reduce the manpower required, the amount of raw material required for the mill and in addition to the average output could still be kept at 30 squares per day which would still be in excess of the standard shingle machine.

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AN INTRODUCTION TO MARKET ASPEN BLEACHED CHEMI-THERMOMECHANICAL PULP

D.A. Cheyne[1]

ABSTRACT.--Market aspen Bleached Chemi-thermomechanical pulp (BCTMP) is one of the fastest growing segments in the international pulp and paper industry. Aspen BCTMP can provide high brightness pulp suitable for printing and writing papers. Accelerated global market growth in paper demand, increases in pulp and paper technology in association with diminishing softwood stocks, have resulted in the increased utilization of aspen as a pulp furnish. Market capacity could exceed 1.5 million tonnes by 1995. Procurement requires advanced knowledge of the stain/decay relationships in the forest. Mill nets, and particularly bleaching costs are adversely affected by defect levels over 40 percent.

INTRODUCTION

Bleached chemi-thermomechanical pulp (BCTMP) is one of the fastest growth products in the international pulp and paper industry. Since its inception as a softwood market pulp in 1978 in Sweden, CTMP market capacity has grown to more than one million tonnes per year (TPY) of softwood and hardwood grades. Tissue, paperboard and now printing and writing (P/W) paper producers are choosing BCTMP over traditional kraft grades as a pulp furnish to improve quality and reduce fibre costs.

Initially, softwood species were the key ingredients for CTMP, however, today aspen (Populus tremuloides Michx.) and aspen/softwood blends are increasingly being used. The best potential market for aspen BCTMP is in the growing printing and writing paper grades; the fastest growing sector of the paper industry at over 3 percent per year (Woodbridge, Reed and Associates 1989). To manufacture P/W grade pulp, brightness and cleanliness are the two most important qualities. For these properties, aspen is superior to any softwood.

ASPEN BCTMP DEVELOPMENT

The growth of aspen BCTMP has come about largely as a result of three major driving forces; increased forest resource utilization, market growth in all areas of pulp and paper, and technological developments related to high yield pulps. The three are interactive rather than independent. Figure 1 illustrates the driving forces.

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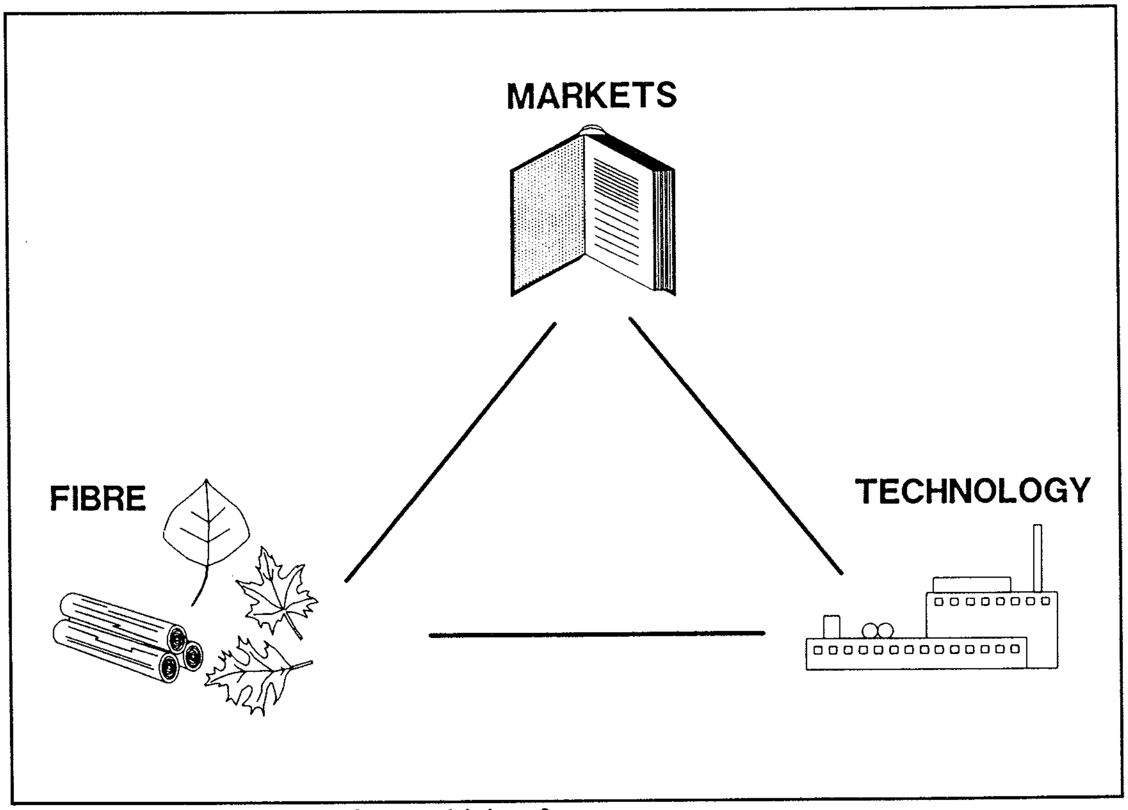

Figure 1.--Aspen market BCTMP driving forces.

FOREST RESOURCES

The harvesting of conifer for pulp and lumber throughout North America in this century has resulted in a receding economic timber line, augmented by inadequate regeneration levels on expansive cutovers. The result as described by some (MacKay 1985) is "cutovers regenerated to junk forests where negligence has left a waste of brush and intolerant hardwoods or weed species."

A recognition of the fact that forests are no longer inexhaustible and require intensive management to provide a sustained flow of fibre for the forest products industry, has led woodlands managers to look at the forest that has evolved and is evolving throughout the northern parts of North America.

These so called "junk forests" or "evergreen forests" represent an important new source of raw materials to a forest products producer dependent on northern hardwoods or specifically aspen. Heterogeneous rather than homogeneous forests present the woodlands manager with a new wrinkle - what to do with large volumes of relatively under-utilized aspen stocks. Part of the answer now lies in the increasing utilization of intolerant hardwoods in chemical and mechanical pulps. Aspen, formally a weed species, is now becoming the most prominent wood species for primarily mechanical greenfield pulp operations, but also incremental kraft pulp expansions.

TECHNOLOGY

Global papermakers realize the benefits of short fibred pulps: increased printability, better formation and improved softness. High brightness paper can be produced from aspen BCTMP with improvements in reversion, cleanliness and extractives content. Over the past decade the growth in chemical and mechanical aspen pulps has led to an increasing comfort level among papermakers who desire aspen in their furnish.

BCTMP, a high-yield mechanical pulp, with yields in the range of 85-95 percent allows for a better utilization of the fibre resource. Traditional chemical pulps (i.e., kraft), have only a 45 percent yield, thus requiring twice the wood fibre per tonne of pulp. Advances in peroxide (H_2O_2) bleaching of mechanical pulp have also augmented the technological growth of mechanical pulp.

MARKETS

Market development has been slow, mainly as a result of the limited amount of market aspen BCTMP available and the historical prejudice against market mechanical pulp within the pulp and paper industry. BCTMP must be specifically tailored to the end-use market and sold on a technical basis, not as a commodity, but as a specialty. Past failures to recognize this fact has stunted BCTMP growth.

Over the past two decades, forest products have experienced steady growth. World paper and paperboard consumption is expected to continue its strong growth, reaching almost 350 million tonnes by 2010, a compound annual growth rate of 2.3 percent. This will require new pulping capacity of approximately 90 million tonnes throughout the world. Most analysts assume that aspen BCTMP will command a percentage of this demand. Figure 2 illustrates this growth forecast.

The greatest growth potential for aspen BCTMP is in the printing and writing paper industry. Japan and Western Europe have been using greater amounts of mechanical pulp in paper furnishes, and North America has traditionally followed their lead in paper trends. The two main factors that have slowed the growth in North America has been the greater amount of integration and the ready availability of inexpensive BKP. However, increasing fibre costs together with increased market growth is expected to fuel an expansion in market mechanical and chemical pulp capacity.

CURRENT PRODUCTION

Market aspen BCTMP is in its infancy, with only two mills in North America producing the pulp for market. Millar Western's greenfield facility in Alberta and Temcell in Quebec, produce approximately 100,000 tonnes per year. A recognition of market potential coupled with competitive power rates and available fibre were the main driving forces behind these mills.

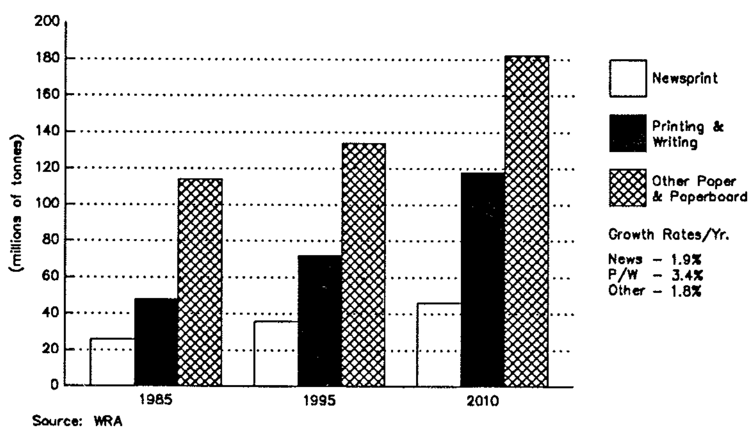

Figure 2.--World paper and paperboard consumption history and forecast 1985-2010.

Within the next 2-3 years, aspen market BCTMP capacity will explode. Six new mills which are under construction or in detailed study, as well as an expansion will add almost 1,000,000 tonnes of new aspen BCTMP capacity.

Temcell - Quebec (Expansion)	100,000
Millar Western - Saskatchewan	220,000
Alberta Energy - Alberta	110,000
Norteck - Saskatchewan	100,000
Shin Ho - Thunder Bay, Ontario	160,000
Cascades - Quebec	100,000
Fibreco - British Columbia	180,000

Potential mills currently under feasibility study could add a further 500,000 tonnes by 1995 throughout North America.

ASPEN WOOD QUALITY

The properties of mechanical pulp are much more dependent on the characteristics of the fibres than they are for chemical pulp. The basic properties of wood and fibres that are important for high-yield pulp are:

- wood density
- fibre length
- fibre diameter
- lignin content and structure
- percent vessel elements
- vessel dimensions
- fibre wall thickness

Although this paper will not deal specifically with these morphological properties of aspen for mechanical pulps, these properties result in the desirability of aspen for P/W papers. Figure 3 illustrates the general properties of aspen compared to other common species in BCTMP.

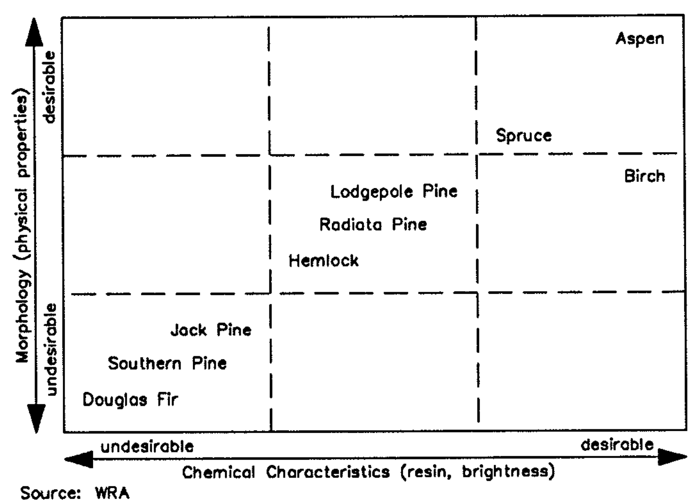

Figure 3.--Relative desirability of species in BCTMP for printing and writing papers.

The other general wood quality factors that affect the desirability of aspen for BCTMP are, bark content, rot, dirt, and stain. Clean aspen fibres are required to produce high brightness pulp; brightness is the critical factor for mill nets.

FIBRE PERSPECTIVE

From a woodlands perspective, the above mentioned four properties are the main concerns in the allocation of an aspen resource for BCTMP production. Fibre requirements can be grossly inflated if these four qualities are adversely exaggerated. Woodlands staff and loggers must be made aware that these adverse affects on pulp quality will directly hinder mill operability and profitability.

The most widespread limitation in restricting the economic utilization of aspen in market BCTMP is the pathogen Fomes igniarius; white trunk rot. The combination of stain and decay caused by the fungi can decrease fibre yields and increase pulp manufacturing costs, particularly bleaching costs. The impacts of stain and decay on aspen BCTMP have been widely studied with reference to H_2O_2 utilization for a given defect level. Figure 4 illustrates results indicative of trends for various defect levels and bleaching levels.

The results show that to attain a minimum brightness of 80, clear wood only requires 0.5 percent bleach, while the 100 percent defect sample would require 3.5 percent bleach. With the market demanding BCTMP in the high 80s, defect levels must usually be below 40 percent, and on average 20 percent if mill nets are not to be adversely affected. On average, a 1 percent increase in bleach equates to a $20/ADMT increase in manufacturing costs. Increased defects will result in increased hogfuel and/or decreased pulp yields. With the BCTMP system designed to produce tailor made pulps, poor quality material entering the system results in poor quality pulp exiting. This differs from a kraft mill where wood fibre quality is not as important.

A BCTMP mill must have a constant supply of uniform quality, fresh aspen. Three day chip storage, 7 day roundwood storage in warm months, weight scaling, woodyard segregation, and efficient chipping and screening operations to assist in eliminating decayed material, are management tools that must be used to ensure quality pulp.

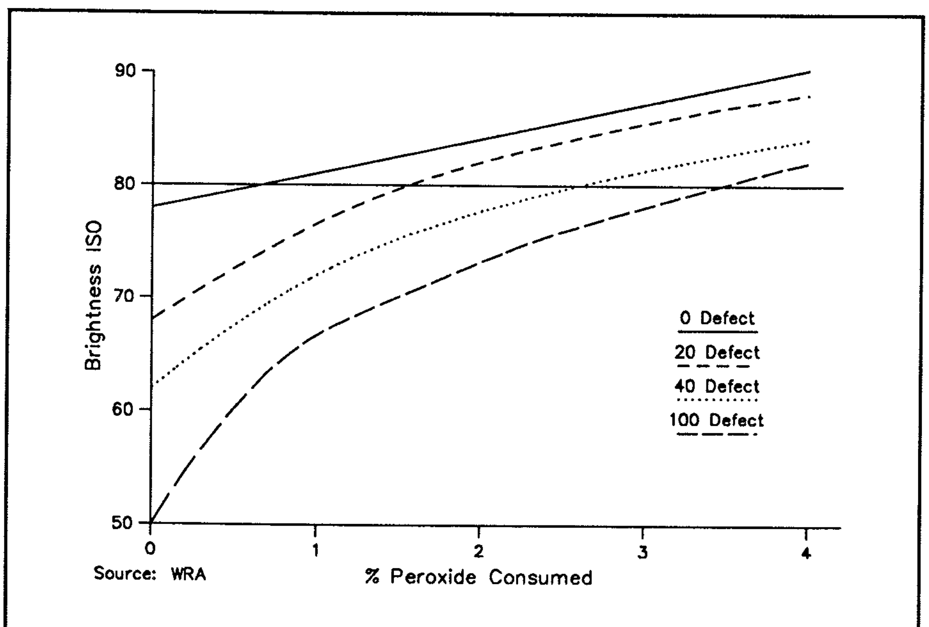

Figure 4.--Effect of defect in aspen on bleachability.

In woodlands strategy, the real difficulties arise in ensuring uniform quality aspen. The variability of decay in aspen, and the uncertainty and difficulty in identifying decayed trees directly results in increased fibre costs, when compared to a kraft mill extracting aspen in the same region.

Any fibre procurement strategy must provide an answer to the question "What proportion of the available resource is usable for BCTMP production". A fibre supply must be available within a given defect threshold at an economic cost to ensure a successful product. With defect usually correlated with age, inventory information becomes very important, to ensure the proper allocation of stands. Figure 5 illustrates the basic scenario that must be developed prior to aspen BCTMP production. An average defect level for aspen BCTMP of between 20-30 percent is a good ball-park figure on which to base a procurement allotment upon.

The woodlands strategy must incorporate the following:

Up-to-date forest inventories particularly on age and site relationships,
Destructive sampling to ascertain stain/decay relationships,
Pulping trials to correspond with field samples,
Cooperative woodlands, rather than single area allocation per mill,
Stand allocation on an end-use parameter,
(i.e., Kraft - Waferboard - BCTMP - Veneer)
Full stand harvesting for all users, do not leave aspen for a "second visit" and risk damaging the stand,
High-grading as a short-term profit enhancement, detrimental to long-term aspen pulpmill procurement,
Limited/uniform mixing of Black poplar (Populus balsamifera L.)
(15 percent maximum by mill volume),
No birch (Betula papyrifera March) utilization or mixing,
No seasoning in the bush,
Education of loggers on quality parameters,
Premium payments for quality.

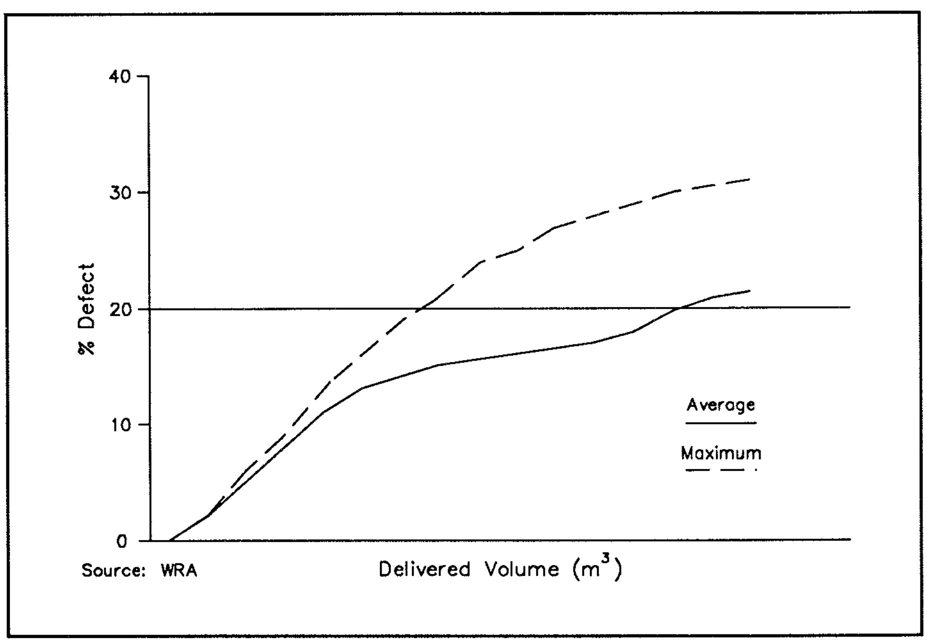

Figure 5.--Fibre supply.

SUMMARY

Market BCTMP for printing and writing papers can be produced from aspen which is clear, stained or decayed. Since the introduction of market CTMP (all grades) in 1978 in Sweden, BCTMP is evolving into a major market pulp throughout North America. Aspen market BCTMP is currently only produced at two mills in North America, but 6 new mills are scheduled to begin production by the early 1990s.

The increase in productive capacity will result in another high-valued use of the once lowly aspen tree. Full forest stand utilization can be realized in areas not only adjacent to kraft mills and/or waferboard plants. However, unlike these two more traditional users of aspen, critical quality parameters (stain and decay) must be ascertained in the forest prior to pulp mill initiation.

The defect laden aspen throughout North America places a commercial penalty not only on the woodlands but the mill nets, particularly in bleaching costs. Thus, the procurement circle must have site specific examinations to detail harvesting costs. An aspen BCTMP mill may be willing to offset bleaching costs through higher extraction costs (low cost in relation to bleaching) to ensure uniform quality fibre.

The advantages of aspen's bright clear fibres compared to softwood fibres clearly outweigh the possible limitations of the resource due to defect. The most important factor associated with the procurement of aspen should be the relative cost of bleaching to maintain a given market brightness level and assure pulp marketability. The woodlands manager should be able to manipulate the fibre basket to provide an uniform aspen supply that the pulp mill manager can work within. A woodyard manager must segregate the roundwood/chips to ensure uniform material input throughout the system.

With the total cooperation of all primary fibre users and allocation agencies, the vastly under-utilized "weed species" in North America can become one of the most important components of the international forest products industry. To quote John Evelyn from his book "Silva or a Discourse of Forest-Trees, and the Propagation of Timber in His Majesties Dominions" in 1662, he said that:

> We had better be without gold than without trees.

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STRUCTURAL LUMBER FROM ASPEN: USING THE SAW-DRY-RIP (SDR) PROCESS

Robert R. Maeglin[1]

ABSTRACT.--Low-density and medium-density hardwoods such as aspen have not been used for structural lumber because conventional processing resulted in excessive warp. The USDA Forest Service, Forest Products Laboratory, has developed a process called Saw-Dry-Rip (SDR) to overcome the warp problem in hardwoods. A simple and practical way of utilizing the abundant hardwood resource, SDR, as the name implies, is sawing flitches, drying them, and then ripping them to desired widths. The small (8 to 14 in.) logs are live sawn (through and through on one plane), dried, and ripped. This paper describes the process and successes in research.

Aspen has not had a good reputation as a stable lumber species. A long history of sawmills cutting aspen for boards and construction lumber is filled with tales of failures and disappointments due to warping. Yet, across the Lake States, Rockies, and Canada are vast forests of aspen that could be utilized in more productive and valuable ways.

Several years ago the Forest Products Laboratory began work on a method to produce straight, stable structural lumber from hardwoods. The technique was named Saw-Dry-Rip or SDR, after the sequence of operations used. This process, now tried on numerous low- and medium-density hardwoods, has proved to be eminently successful. Extensive study of yellow-poplar studs at several locations has shown 90 to 100 percent of pieces manufactured by SDR to be of STUD grade (Denig and Wengert 1985; Maeglin and Boone 1983; NHPMA 1978; Weik, et al. 1984). Results for other species such as paper birch (Larson, et al. 1984), red alder (Layton 1982), and cottonwood (Trachsel 1982) have been very good, as have limited trials on basswood, red maple, black willow (Maeglin and Boone 1985), sweetgum, blackgum, and sycamore. We have done extensive work with aspen, and that is what this report discusses. Aspen has a tremendous potential as structural lumber, and it can be manufactured into a good, stable product using SDR.

THE SDR PROCESS

SDR is a simple process based on well-known manufacturing techniques combined, in a different order, to account for wood structure and stresses (Hallock and Bulgrin 1977; Maeglin and Boone 1983). In SDR, small logs are live sawn (with all cuts parallel) into 7/4 flitches; the flitches are lightly edged for a compact kiln load, dried, and then ripped to dimension after drying. They are finally planed to finished size. The difference in the processing order is that conventional manufacturing cuts the lumber to dimension, with an allowance for shrinkage and planing, before drying instead of after drying.

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Live sawing has been used for centuries, and it is still used for hardwoods, but primarily to keep boards together in log form for grain matching. This method of sawing also promotes some stress relief during the drying process.

Drying in SDR may be done in several ways: conventional kiln drying, high- temperature kiln drying, air drying, or dehumidification (Boone and Maeglin 1980; Larson, et al. 1984). The greatest gains in quality are due to live sawing, but drying can have additional influence on stress relief. Drying of aspen for SDR processing is discussed in a paper by Sidney Boone in this proceedings.

Longitudinal growth stresses cause conventionally processed lumber to warp. Stresses are formed in the tree, as new wood is laid down, and are in perfect balance within the stem. Longitudinal growth stresses are tension at the periphery of the tree and compression at the center (Fig. 1). New fibers formed by the cambium are simple thin-walled tubes that are immediately glued together by lignin, a natural adhesive. Secondary walls are formed in the cells and would cause the fibers to shorten as cell diameter increased, but the restraint due to lignin bonding causes tension stresses to form. As the tree grows in circumference, accumulated tension stresses induce compression stress at the center of the tree. A continuum of stresses results with high tension at the outside, diminishing to a neutral zone and then increasing in compression to a high at pith.

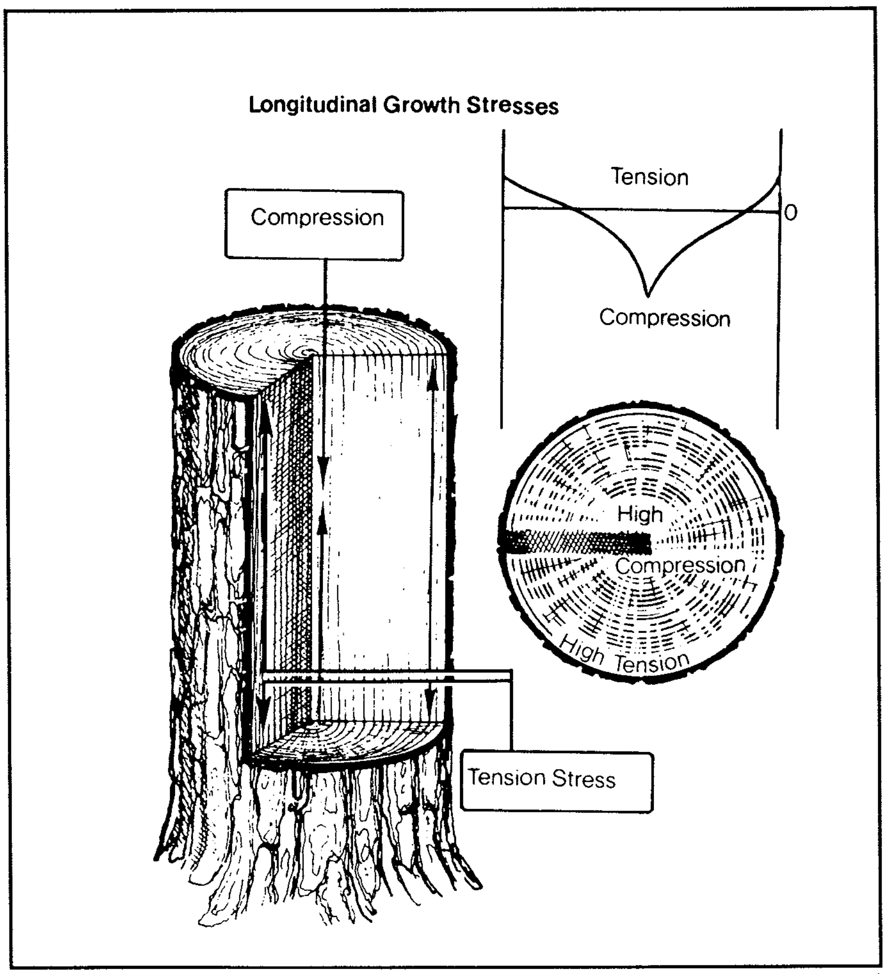

Figure 1.--Longitudinal growth stress patterns in hardwood trees and logs. (ML83 5581).

If a 2 by 4 is cut from a green log, stress differentials acting on the piece will cause it to warp. The tension side will shorten, and the compression side will lengthen (Fig. 2). The 2 by 4 will have warp that will be difficult or impossible to remove. How, then, does SDR work? SDR works in four basic ways as shown in Figure 3.

METHODS

The work reported in this paper was divided into two parts: laboratory trials and commercial evaluations.

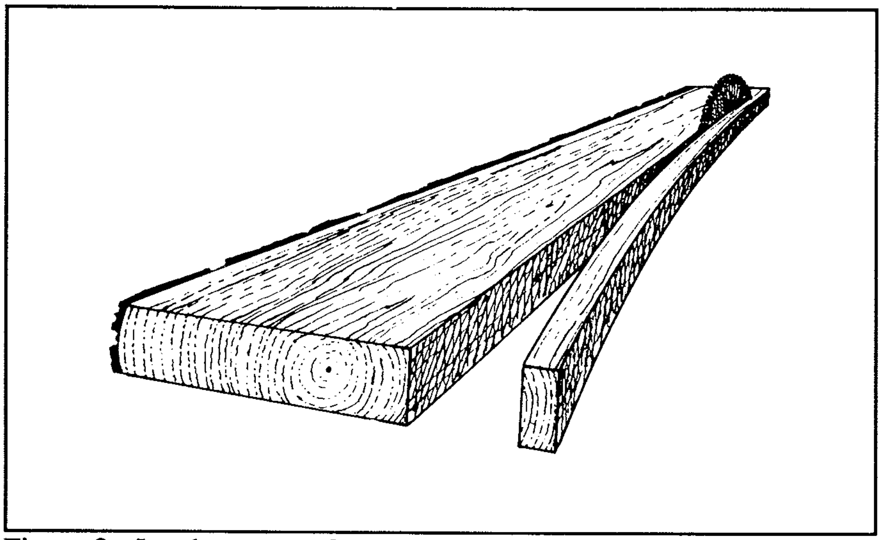

Figure 2.--Lumber sawn from hardwood logs exhibits stress release (warp) on cutting. The side under compression lengthens and that under tension contracts on sawing, resulting in warp. (ML 83 5582).

What Makes SDR Work?

1. Stresses are Balanced by Live Sawing
2. Wide Flitches Restrain Warp
3. Drying Stresses Offset Growth Stresses
4. Lignin is Plasticized at High Temperature

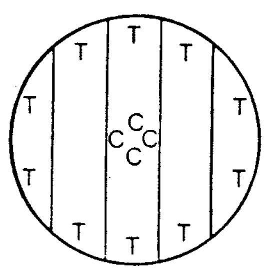

Figure 3.--Four factors contribute to the success of SDR.

LABORATORY TRIALS

All laboratory trials were attempts to develop a suitable high-temperature drying schedule for 7/4 aspen flitches. No controls existed against which the trials could be compared. Rather, the trials were compared to one another using STUD-grade warp criteria and moisture content (MC) for comparison (NHPMA 1978).

Eighteen trials were made using various high temperatures, times, and kiln conditions (Table 1). All materials dried were 7/4 live-sawn aspen flitches, which were dried before ripping into studs. The studs were evaluated for quality by measuring warp and MC.

Table 1.--Kiln conditions and schedules for 18 aspen drying trials.

Trail Number	Temperature (°F) Dry-bulb	Wet-Bulb	Drying Time (h)	Equalizing Time[1] (h)	Average MC (percent)
1	235	190	28	44	15.7
2	35	190	28	48	23.8
3	260	190	28	49	20.9
4	260	190	32	44	12.4
5	235	190	48	23	17.3
6[2]	250	190	48-8	--	8.0
7	240	190	45	22	--
8[3]	240	190	40	30	11.7
9	250	190	42-8	24	7.7
10[4]	235	190	8	--	16.2
11[5]	240	(Vents open)	32	24	10.4
12	240	(Vents open)	44	29	5.9
13	210	(Vents open)	120	24	7.9
14	240	(Vents open)	45	29	6.1
15[6]	--	--	--	--	8.3
16	--	--	--	--	8.8
17	240	(Vents open)	45-9	29	19.4
18	240	(Vents open)	45-9	29	9.5

[1]All equalizing was done at 200°F dry bulb and 188°F wet bulb.

[2]A split schedule with a high-temperature/equalizing-high-temperature cycle. The times at high temperature are in sequence under "Time." This footnote applies to trials 6, 9, 17, and 18.

[3]Lumber steamed in the kiln for 4 hours before drying started.

[4]Lumber air-dried to 28 percent MC before kiln drying.

[5]Vents on the kiln were held open--no wet-bulb control during drying. This footnote applies to trials 11 to 14 and 17 to 18.

[6]Conventional schedule FPL T10-E6 (Rasmussen 1961). This footnote applies to trials 15 and 16.

Warp measurements included crook, bow, and twist. Crook is a deviation edgewise from a straight line drawn from end to end of a piece. Bow is a deviation flatwise from a straight line drawn end to end of a piece. Twist is a deviation flatwise, or flatwise and edgewise, in the form of a curl or spiral so that the four corners of any face are not in the same plane. Each piece was measured to the nearest 1/32 in. for the three warp types. (Because measurements were made to the nearest 1/32 in., values are reported as multiples of 1/32 in.) The warp measurements were used to calculate averages and to determine acceptance for STUD grade. Limits of warp for STUD grade are as follows: for 2 by 4s and 2 by 3s, crook 1/4 in., bow 3/4 in., twist 3/8 in.; and for 2 by 2's, crook 3/4 in., bow 3/4 in., twist 3/16 in.

Moisture content was measured at three locations on each stud, about 1 ft from each end and near the middle. The MC was obtained using an insulated-pin, resistance-type moisture meter. The pins were driven to a depth of 3/8 in.

For 10 of the 18 trials, the dried studs were placed in storage for a minimum of 60 days. The dried studs were in an open shed, under roof, exposed to ambient weather conditions and humidities.

COMMERCIAL EVALUATIONS

Four commercial mill evaluations were made using aspen SDR. The four mills used standard dry kilns and maximum temperatures of 160°F to 200°F or higher. Instrumentation in the kilns did not allow exact temperature recording above 200°F. One mill manufactured 2 by 3 screeds for gymnasium flooring underlayment; a second, 2 by 3, 2 by 4, and 2 by 6 studs; a third, doorframe parts; and a fourth, random-length 2 by 4 lumber.

The screed manufacturer ripped the flitches on a gang-flooring ripsaw, crosscut the 8-ft-long pieces into 4-ft lengths, and treated them with a preservative dip; 24,000 board feet of lumber was processed. A company lumber grader evaluated the screeds for straightness and general quality according to company standards.

In the stud manufacture, flitches were ripped on a straight-line ripsaw. An Association lumber grader graded the 12,000 ft of studs, evaluating warp, knots, slope of grain, splits, checks, and MC.

In the manufacture of aspen doorframe parts, two drying schedules and two sawing patterns were used. The lumber was predried to about 20 percent MC. Grade-sawn lumber was dried at a maximum of 160°F while live-sawn flitches were dried at 160°F and 200°F or higher. Both grade-sawn lumber and live-sawn flitches were gang ripped, to 2-3/4-in. widths, after drying. Randomly selected ripped pieces were then measured for crook, bow, and twist, as was done in laboratory trials. The average warp values were then compared for the three treatments. About 141,000 board feet of aspen was processed.

In the production of random-length 2 by 4 lumber from Rocky Mountain aspen, flitches were sawn, dried, and stored in the fall of 1983 for ripping in the spring of 1984. Drying was at a maximum temperature of 190°F for 7 days. A random selection of 202 flitches was measured for MC before storage indicating an average MC of about 11 percent, with only seven pieces exceeding the 20 percent MC. About 15,000 board feet of flitches was manufactured.

RESULTS

LABORATORY TRIALS

Warp and Rejects

In our laboratory trials, we manufactured nearly 1,400 studs of which only 38 (2.7 percent) were rejected based on STUD-grade warp limits (NHPMA 1978). Of those rejects, 24 were from one trial (trial 17) (Table 2). If that trial is eliminated from the data, only 1.1 percent of the pieces were rejected from the STUD grade immediately after processing. Trial 17, which consisted of flitches from the log centers, was dried without wet-bulb control and with kiln vents open at all times--a severe drying condition. Trial 18 was dried under the same severe conditions and also consisted of pieces from log centers. Because of the severe conditions of drying, it had the second highest number of rejects. Without drying trials 17 and 18, there were 1,240 studs. For those 1,240 studs, less than 0.6 percent were rejected due to warp. By way of contrast, trials 13 and 14, which consisted of outer flitches from the logs, had only one reject between them, even though subjected to severe drying conditions.

Out of the 18 drying trials, 10 were placed in extended storage. For the 10 trials placed in storage, an overall increase in rejects, from 0.4 percent initially to 6.2 percent, occurred after storage (Table 2). While this increase is significant, the quantity of rejects can be contrasted to reports from several mills of 60 percent rejects before storage.

Average warp is another way of considering the effect of SDR processing on stud quality (Table 3). For 2 by 4s, the average crook was 1.4/32 in. for all 18 trials. Trial averages varied from 6/32 (trial 17) to 0.32/32 in. (trial 14). If trials 17 and 18 are eliminated from the data, the average crook for 812 2 by 4's is 0.89/32 in.. Trial 17 with 6/32 of average crook had 25.8 percent rejects, while trial 14 with 0.32/32 average crook had no rejects.

Most rejects are based on excessive crook, but bow and twist may contribute also. Average bow for 812 2 by 4's was 5.4/32. This is comparable to the amount of bow found for other species evaluated for SDR (Erickson et al. 1986; Layton 1982; Maeglin and Boone 1983; Trachsel 1982). No aspen 2 by 4's were rejected due to bow for initial measurements, and only two 2 by 4's were rejected after storage. Only two 2 by 3 and 2 by 2 studs were rejected due to bow initially and only four after storage. Average twist for 2 by 4's was 1.3/32, and no rejects were due to twist for the nearly 1,400 mixed-size studs.

Moisture Content

Final MC and drying problems are the major concern with aspen; this seems to be due to bacterially infected wetwood (Ward 1976; Ward and Pong 1980). Aspen typically contains a fairly high percentage of bacterial wetwood; perhaps 50 percent of all pieces have some present. We did not quantify the amount of wetwood present in the lumber from our laboratory trials or the mill evaluations. If wetwood is present in a flitch, the flitch usually does not dry uniformly. It is not uncommon, in stock with wetwood, to find streaks, some no wider than a pencil, or wet pockets with MCs of up to 200 percent. On ripping, the wet pockets or streaks may be exposed. As time elapses, the lumber dries and shrinks causing after-ripping warp to occur. This is the major cause of increased rejects after storage. The paper by Sidney Boone, included in this proceedings, discusses selection of logs to minimize wetwood problems.

Moisture content of studs varied greatly, from nearly ovendry (0 percent) in some cases to well over fiber saturation (>30 percent) in others. The best quality studs had the lowest average MC with the exception of trial 18 where the quality and MC were both low (Table 2).

Table 2.--Moisture content and reject data by drying trial for aspen 2 by 4, 2 by 3, and 2 by 2 studs.

Trial number	n	Average MC (percent)	Number rejects[1] Initial	After storage
		STORED		
1	154	17.0	0	7
2	38	23.1	0	3
3	48	17.3	1	1
4	54	12.9	0	8
5	73	17.9	0	7
6	87	8.0	0	2
7	52	10.0	0	3
8	76	11.8	1	4
9	38	7.1	0	2
10	42	16.2	1	4
Total	662	--	3 (0.4 percent)	41 (6.2 percent)
		NOT STORED		
11	102	11.1	0	
12	55	6.3	1	
13	86	7.2	1	
14	64	6.0	0	
15	142	8.3	0	
16	129	8.6	2	
17	93	18.1	24	
18	66	7.3	7	
Total	1,399	--	38 (2.7 percent)	

[1]Values in parentheses are the percentage of rejects based on total n.

COMMERCIAL TRIALS

Since 1979 we have conducted four commercial trials using aspen. When screeds were evaluated in the first mill study, the company inspector said the product looked very good. The pieces were straight and contained relatively few defects compared to hemlock screeds normally manufactured. Moisture content was not evaluated.

The studs manufactured in the second study were of exceptionally high quality, but of the 12,000 board feet of studs produced, nearly 30 percent was rejected for excessive MC. The pieces exceeding the MC limits (19 percent MC) were of the same grade proportions as the dry material according to the grader's report. The grade recovery of suitably dried material from the woods-run logs (8- to 15-in. diameter) was 83 percent STUD and BETTER for 2 by 3s, 89 percent STUD and BETTER for 2 by 4's, and 95 percent Structural Light Framing No. 2 and BETTER for 2 by 6 studs (Table 4).

Table 3.--Warp limits for STUD grade as shown in NHPMA (1978) Standard Grading Rules[1].

Size	Warp (in.) Crook	Bow	Twist
2 by 4	8/32	24/32	12/32
2 by 3	8/32	24/32	12/32
2 by 2	8/32	24/32	6/32

[1]Excluding pieces with excessive MC.

In the evaluation for door parts (Huber et al. 1984), crook was reduced by 40 percent when the SDR aspen was dried at 160°F and by 60 percent when dried at 200°F or higher, compared to grade-sawn lumber dried at 160°F. Bow was reduced by 91.5 percent when dried at 160°F and by 21 percent when dried at 200°F or higher. Twist was not consistently reduced by SDR, but the levels of twist were extremely low. Twist was reduced 9.5 percent when the 200°F of higher temperature was used for drying. When the SDR aspen was dried at 160°F, twist was 57 percent greater than for the grade-sawn material, but the average of the greater twist was only 1/32 in. and not of practical importance. The distribution of warp in the door parts evaluation is shown in Table 5. The level of warp in the grade-sawn/160°F treatment is low compared to that for studs because the pieces ripped and measured for warp came from wide boards. Had the 2-3/4-in. pieces been cut green and then dried, the warp would have been much greater than for studs.

Table 4.--Grade mix of aspen studs manufactured in a commercial trial[1].

Size (in.)	Volume (board (feet)	Grade	Percentage in grade
2 by 3	1,350	STUD and BETTER	83
2 by 3	285	Utility and rejects	17
2 by 4	3,480	STUD and BETTER	89
2 by 4	420	Utility and rejects	11
2 by 6	2,620	No. 2 and BETTER	95
2 by 6	140	No. 3 and rejects	5

[1]Excluding pieces with excessive MC.

Table 5.--Amounts of crook and twist in aspen door-part lumber.

Warp (in.)	Pieces in warp category (percent) Grade sawn/160°F	Saw-Dry-Rip/160°F	Saw-Dry-Rip/200°F or higher
Crook			
0.0	65.0	75.8	81.5
0.1	22.3	17.4	15.9
0.2	8.7	5.8	2.0
>0.2	4.0	1.0	0.6
Twist			
0.0	82.1	76.4	84.2
0.1	15.4	16.6	13.1
0.2	2.0	5.0	2.3
>0.2	0.5	2.0	0.4

In the evaluation for random-length lumber of western aspen, we manufactured about 15,000 board feet of 2 by 4's in New Mexico. This material was manufactured to build two truss-framed structures. The yield of over 15,000 board feet came from 10,000 board foot scale (Scribner Dec.C) of logs. The grade mix of the random length lumber was similar to that of softwood production. Truss frames for the buildings were assembled and stored for about a year before being erected. These buildings were probably the first totally engineered structures made of aspen. These buildings are located on the Guadalupe Ranger District of the Lincoln National Forest in New Mexico.

DISCUSSION AND CONCLUSIONS

Results of the laboratory studies on aspen SDR indicate two major things:

1. Aspen is difficult to dry because of wetwood.

2. In spite of drying problems, high-quality structural lumber can be produced using SDR.

The drying of aspen can be advanced considerably by sorting to eliminate obvious wetwood logs. Further, if flitches with obvious wetwood were separated from normal wood, each type could be dried on a separate schedule, resulting in more uniformity. Wetwood is generally identified by its yellow, brown, black, or gray coloration as opposed to the creamy-white of normal wood; however, up to 25 percent of wetwood may have no color indicator.

Trials 13, 14, 17, and 18 help to point out the wetwood problem. Trials 13 and 14 used flitches from the outer portion of the log, i.e., generally normal wood. The drying schedules for trials 13 and 14 (Table 1) worked well, resulting in low MC and few rejects. Trials 17 and 18, however, used inner flitches, with wetwood, from the same logs as those used in trials 13 and 14. The results were plainly a disaster. The flitches were collapsed and honeycombed, and the resulting studs were badly warped. The drying conditions in trials 13, 14, 17, and 18 were quite severe, but the difference in stud quality between normal wood and wetwood varied considerably under similar kiln conditions.

The fact that in most cases (trials 1 to 16) the studs were good, even with erratic drying, speaks well for the SDR process. The high proportion of better grades achieved with aspen using SDR (Table 5) makes the process even more attractive, but the problem of uniform MC needs to be solved. Trials 15 and 16, done under longer term conventional drying schedules, had low and uniform MCs, as did the predried lumber from the door-parts evaluation and the lumber dried at less than 212°F from the random-length evaluation. This would indicate that using a longer or more conventional drying schedule would help ensure quality structural lumber from aspen.

Aspen has a lot of potential for structural lumber if processed using the SDR concept. It is bright in appearance, easy to work, nails well, and has sufficient strength even for engineered buildings such as the truss-framed structures. SDR does, as shown in the laboratory and industrial trials, produce straight and stable studs. It is necessary, however, to dry the material uniformly.

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SORTING ASPEN BOLTS AND DRYING ASPEN FLITCHES FOR SDR

R. Sidney Boone[1]

ABSTRACT.--Log sorting is necessary when processing aspen saw-dry-rip (SDR) to select optimum log diameter and to minimize number of logs with dark-colored centers. Wetwood, which is difficult to dry, is commonly associated with these dark centers. SDR processing involves drying 7/4- to 8/4-thick live-sawn flitches. Drying the flitch and then sawing studs produces straighter studs than sawing first and drying in stud form. High-temperature kiln drying (230°F to 240°F) has given good results with several species (such as, basswood and yellow-poplar). For species likely to contain wetwood (aspen, cottonwood, willow), high-temperature drying is not recommended. A kiln schedule for aspen with maximum temperatures of 190°F to 200°F followed by equalizing at 12 percent EMC is suggested.

SORTING ASPEN BOLTS

Sorting of logs or bolts is necessary when processing aspen for the saw-dry-rip (SDR) process for two reasons: (1) to select optimum log diameter and (2) to minimize the number of logs with dark-colored centers or hearts.

We must sort for size because we have found that logs with diameters from 7 to 14 in. produce the straightest pieces when manufactured by the SDR process. Logs smaller than 7 in. are not usually profitable to saw, and those that are much larger have large knots, more decay, and increased cross grain and thus give poorer results than those in the 7- to 14-in. category.

Sorting to minimize the number of logs with dark-colored centers is necessary because this dark-colored wood usually is associated with or contains "wetwood" and is difficult to dry. This sorting is related specifically to aspen and not to the SDR process.

Aspen has a reputation for being difficult to dry. This is usually due to the presence of wetwood or wet streaks, which in turn are associated with the darker brown or black wood near the center of the log. White bright aspen sapwood or normal heartwood containing no wetwood is relatively easy to dry. Several other species, including cottonwood and willow, frequently have streaks or pockets of wetwood that present various drying problems.

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WHAT IS WETWOOD?

Wetwood is caused by a bacterial infection in the living tree. Anaerobic bacteria enter the living tree through roots, branch stubs, and various types of wounds to the tree. The infected area is commonly found as pockets or streaks, frequently in the heartwood, in the heartwood-sapwood boundary area, and around knots or branch stubs. Wetwood frequently has a darker color than normal heartwood, which is the reason for the terms "false" or "pathological" heartwood. Wetwood may also have a water-soaked translucent appearance. In general, wetwood is higher in moisture content than the adjacent normal wood. Regardless of external appearance, wetwood differs from normal wood in physical and chemical properties and generally is more difficult to dry (Knutson 1973; Ward and Zeikus 1980).

PROBLEMS WITH DRYING WETWOOD

These areas or zones of bacterial infection dry much more slowly than normal wood because of low permeability. Even when wetwood boards reach the desired average moisture content, there frequently is an uneven distribution of moisture where the normal wood is very dry, but the streaks or pockets are still above the fiber saturation point of 30 percent. This may result in the total piece being rejected because the infected streaks or pockets exceed the moisture content limits set for the product. These streaks or pockets may also show collapse or severe honeycomb, or both, during drying. When dried flitches containing wetwood areas are ripped, these high-moisture-content areas can be exposed. Subsequent drying of the exposed surface in storage or in use may cause excessive shrinkage or warp of the surfaced piece, such that it no longer meets warp or size requirements.

We should recognize that if the logs are well sorted to minimize the amount of wetwood, drying problems are greatly reduced. However, we should also be aware that we cannot spot every bad log, and an unpublished study conducted at the University of Minnesota suggests that up to 15 to 20 percent of the "good looking" logs may have streaks or pockets of wetwood.

WHEN TO SORT AND WHAT TO LOOK FOR

We suggest that sorting should start in the woods. In fact, most of the sorting should be done there. The material rejected for SDR could then go to pulp or particleboard plants where there is less concern with problems caused by wetwood.

The amount or intensity of sorting needed may vary from one geographic area to another and for material from one site to another. Certain clones of aspen may be more likely to exhibit wetwood infection than others, and since aspen readily reproduces from root sprouts, this may be related to the site. If sorting in the woods is not possible or practical, then sorting should be done at a concentration yard or on arrival at the sawmill.

Sorting by visual inspection of the ends of logs or bolts is suggested. Good logs have no discoloration and are creamy white in color. A typical bad log would have a discolored, dark-chocolate-brown to black area, usually in the center of the log, which may constitute 25 to 40 percent of the total surface area of the log end. A typical marginal log would have a moderately discolored, coffee-with-cream-colored area, which may constitute 15 to 30 percent of the total surface area of the log end. Logs with darkly discolored areas will almost surely have drying problems. Marginal logs with moderate discoloration will likely have drying problems, but can generally be accommodated in processing if their total numbers are not overwhelmingly large. For best results with aspen for SDR, logs must be sorted for minimizing wetwood. Use of woods run logs is not recommended.

DRYING METHODS FOR ASPEN FLITCHES

The saw-dry-rip (SDR) process was developed for processing low- and medium- density hardwoods for structural lumber. When we discuss drying methods for the SDR process, we must think in terms of drying flitches. These flitches are the result of live-sawing logs that are generally 7 to 14 in. in diameter. The flitches typically have some bark on one or both edges. These may be lightly edged to make a more compact stack for drying.

Early SDR studies at the Forest Products Laboratory (FPL) with yellow-poplar (a species widely found in the southeastern United States), basswood, and red maple suggested that high-temperature drying (230°F) of flitches produced straighter studs than did conventional-temperature (180°F maximum) schedules (Maeglin and Boone 1980, 1981, 1983). Later studies using SDR with yellow-poplar, and paper birch have shown that the most benefit is derived from drying as a wide flitch than from using high-temperature drying (HTD). These studies however, support one of the original hypotheses that of offsetting drying stresses against growth stresses (Larson et al. 1984; Maeglin and Boone 1985, 1988; Weik et al. 1984).

We have suggested that better results (straighter studs) can be obtained by drying live-sawn flitches by any of the traditional drying approaches--air drying, low temperature (for example dehumidification), conventional temperature (maximum 180°F to 190°F), and HTD (230°F to 250°F)--than by drying conventionally sawn studs by these same drying methods. Different species will likely have differing optimum drying approaches, but we emphasize that SDR processing is not limited to high-temperature drying.

For some species, such as yellow-poplar and basswood, HTD yields positive results. However, for aspen, cottonwood, willow, and other species prone to have wetwood, we cannot now recommend HTD. It seems to increase the amount of collapse and honeycomb and, because of large moisture gradients in the piece, requires unusually long equalizing times.

As indicated previously, aspen has a long history of difficulty in drying to uniform moisture contents. Articles in the literature have discussed this problem since the mid-1940s. Both Canadian and U.S. researchers have suggested various approaches to drying aspen, but none have been overwhelmingly successful (Huffman 1972; Mackay 1974, 1976, 1978; Mackay et al. 1977; Ward 1976, 1986). Bright sapwood of aspen, without wetwood, is no problem to dry. The pieces with wetwood are the real problem, which is why we discussed previously why and how to sort the aspen bolts and logs to minimize the amount of wetwood to be dried.

KILN SCHEDULE CURRENTLY RECOMMENDED FOR ASPEN FLITCHES

Based on FPL research, and several commercial trials, we are currently suggesting a schedule similar to the following (Fig. 1) for drying aspen flitches containing a minimum amount of wetwood (that is, sorted bolts).

--Raise dry-bulb temperature to 180°F as fast as possible, ideally in 3 to 4 hours.

--Raise wet-bulb temperature to 130°F to 140°F, thus giving an equilibrium moisture content (EMC) of 3.5 to 4.5 percent.

--Change dry-bulb temperature to 190°F to 200°F over 8 to 10 hours, if possible.

--Provide a minimum airspeed through the load of 400 ft/min (800 ft/min is preferred) and reverse fans every 6 to 8 hours.

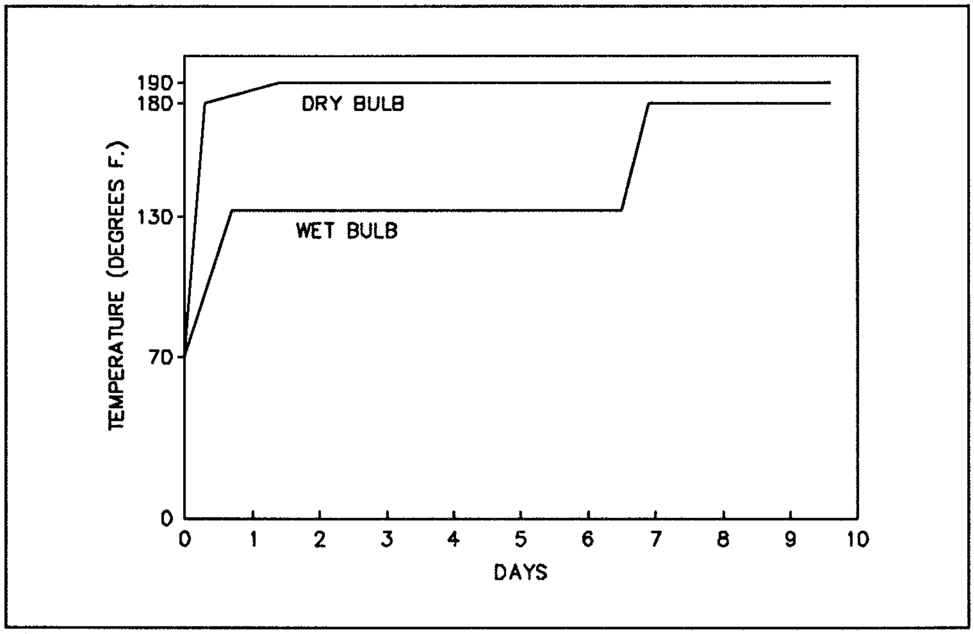

Figure 1.--Generalized kiln schedule for drying aspen flitches.

--Have an equalizing period of approximately 24 hours at 12 percent EMC at end of drying period to minimize high moisture content in wet pockets. If stock appears to have substantial amounts of wetwood, longer equalizing periods may be necessary.

--Expect more even drying with narrow loads (7 to 8 ft in track-loaded kiln) than with wide loads such as the 24-ft air travel typically found in package loaded kilns.

--Expect this procedure to take 7 to 10 days, depending on initial moisture content of flitches and length of equalizing time needed to provide stock with a final moisture content of 12 to 15 percent.

If lower maximum temperature or substantially lower airspeed must be used because of equipment limitations, then longer drying times will be required.

AIR DRYING OF ASPEN FLITCHES

Air drying will work in the technical sense but may have limitations for business reasons. Drying will require 2 to 3 months of good spring-summer drying conditions, considerably longer if put out on sticks in the fall or early winter.

It may be difficult to dry down to 12 to 15 percent moisture content as suggested, though 15 to 19 percent should not be too difficult. A larger inventory must be retained, and with interest rates at 10 to 12 percent, that may not be an attractive practice.

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OPPORTUNITIES FOR ASPEN FOR FURNITURE

Hugh W. Reynolds and Patrick K. Donahue[1]

ABSTRACT.--Aspen is by far the most important hardwood in Minnesota. In addition to paper and oriented strandboard, approximately 100 million board feet of aspen are sawn annually. NRRI has a research and development program to convert the best 10 percent of this aspen lumber to fine furniture. Since this 10 million board feet of lumber is only one-quarter of one percent of the total U.S. furniture used we are hunting for a small market niche.

Aspen is soft with low crushing strength so we have developed a high strength joint by laminating thin lumber to make jointed furniture part assemblies. Aspen furniture makers will buy parts from hardwood dimension companies specializing in this type of laminated parts. Finishing of the aspen parts is a part of the research and development program. This new furniture technique has been reduced to practice with a line of RTA upholstered furniture.

INTRODUCTION

Is aspen a money tree for the furniture and kitchen cabinet industries? This presentation will introduce part of the research being done at the Natural Resources Research Institute (NRRI) to increase the range of uses and thus total use of aspen lumber and aspen veneer as a raw material in two market segments: furniture and kitchen cabinets.

Aspen is by far the most important hardwood in Minnesota. While most aspen is used in making paper and oriented strandboard (OSB), a large amount, almost 100 million board feet annually, is sawn to lumber. The highest quality lumber, #1 Common & Better, is often used to make products such as pallets that could use lower quality lumber. The NRRI seeks to make greater use of the high quality aspen lumber in the furniture and kitchen cabinet industries. For aspen to be used in these markets it must perform a durable-decorative function. Our goal is to market this wood, which many people see as a "junk-wood" by converting it into a form which yields the highest value-added compared to other wood fiber products.

The development of aspen as a furniture and cabinet wood is essential for the survival of profitable mid-priced domestic produced furniture and industry. We need to convince the product managers to introduce suites of furniture and product lines featuring aspen. To do this we need a vigorous promotional effort to target this group, but first we must develop a saleable aspen product line.

Estimates of the annual consumption of high quality hardwood lumber by the furniture and kitchen cabinet manufacturers vary widely. We conservatively estimate that 10 percent of the aspen lumber sawn in Minnesota is high quality, #1 Common & Better. But this 10 million board feet of high

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quality aspen is only one-third to one-quarter of one percent of the three to four billion board feet of hardwood used by these manufacturers. So we are hunting for a small market niche in which to use Minnesota aspen and not trying to establish another Drexel or Merillat.

We have chosen ready-to-assemble (RTA) type furniture as one market niche for Minnesota high quality aspen. Dr Steve Sinclair, of VPI in Blacksburg, Virginia, has recently completed an RTA furniture survey. Sinclair found that RTA is becoming very popular and is the fastest growing segment of the furniture industry. Customers are asking for higher quality RTA and are willing to pay the higher prices. Most RTA is case goods made from medium density fiberboard. We are looking at higher quality RTA furniture made from lumber as our market niche.

VALUE-ADDED PRODUCTS

At present there are not enough high value aspen products made in the state to absorb the 10 million board feet of high quality aspen sawn each year. We do not expect that the establishment of a market for the high quality aspen will cause more high quality lumber to become available. Instead we aim to deflect the currently available high quality lumber into high value added products.

As an example, $450 of high quality aspen lumber can be made into furniture worth up to $1800, leading to additional local employment. Looking at it another way, Table 1 gives the number of board feet of material required to make $1,000 of product. This focusses on the improved efficiency and thus the importance of aspen as a furniture wood.

CHALLENGES IN USING ASPEN

Aspen has an advantage in its price and availability. Also, aspen has a very bright white color, is light, and machines well when correctly dried. However, it is not hard to find fault with aspen for furniture and cabinet manufacturing applications. Aspen is soft and of low strength compared to traditional furniture woods. While it seems true that aspen hardens with age the process of hardening is not understood. We intend to study this in the future. Aspen has history of wet pockets, being hard to kiln dry, difficult to knife machine without fuzzing, i.e., raised grain, difficult to sand, and finally all of the above make it difficult to finish, i.e., paint, stain, and top coat. The above challenges must be answered to produce a final finished product which is of interest to the decision maker - the furniture and kitchen cabinet product manager.

For any company to make a product line decision we need to provide a completely finished product with an attractive price point. If this is done, we can expect the markets to develop themselves. The estimated price of finished aspen furniture components makes aspen one of the few North American hardwoods that can compete with offshore woods, such as Malaysian-rubberwood, providing the above challenges can be met. Therefore, we can convert our low value wood into something of true value to the OEM and ultimately the customer.

Following the furniture engineering procedures established by Dr. Carl Eckelman of Purdue University we have determined that aspen cannot be used to made to make furniture using conventional joints. The crushing strength of aspen is too low to use dowel or mortise and tenon joints. We have devised a new way to make laminated aspen joints to overcome the aspen crushing strength problem.

Table 1.--Material required to make $1,000 of product.

Product	Material Required (Bd. ft.)
Boxes and crates	7,000
Flooring	4,000
Millwork	2,000
Furniture & kitchen cabinets	750

RESEARCH AND DEVELOPMENT

ASPEN RTA FURNITURE PRODUCTION PROCESS

In this process, we start with thinwood aspen pieces 3/8- or 1/2-inch thick. The piece length depends upon the furniture design but the piece width depends upon the joint strength requirement. The pieces are then laminated using conventional gluing techniques. The glued pieces, now as a flat assembly, are machined to completed parts using CNC routers. In this way the joints are a type of mortise and tenon with the mortise and tenon wider than the part width. It is this increase in joint width that creates the high strength joint.

In conventional furniture parts manufacturing, kiln dried lumber is cut and ripped to make defect free rough dimension parts. The parts are than machined to make the completed parts. These parts are joined to make the furniture. In most furniture the joints occur at high stress points, such as where a chair rail is joined to the chair back post. The furniture generally fails at a joint and not within the individual part.

Our aspen furniture is similar, the kiln dried lumber is cut and ripped to make the thinwood pieces, which are then laminated together to form a jointed rough dimension part. These "rough dimension parts" are then machined to make complete jointed parts. These parts are joined together at low stress areas to make the furniture. This joining can be done permanently with a glued lap joint or with RTA fasteners.

While aspen furniture techniques appear to be costly we have found that the cost of laminating balances out with the cost of conventional joint making. Our aspen furniture technique lends itself to part purchasing by the furniture maker. The furniture maker will buy the thin wood pieces from hardwood dimension manufacturers. The dimension manufacturers that specialize in drawer parts can furnish the thin wood pieces at effective costs. The furniture maker can send his rough dimension parts assemblies to machining centers specializing in CNC router work. Following the return of the machined parts the furniture maker will finish and assemble the components. In this way the furniture maker can concentrate on furniture design, finishing and selling with a minimum investment in wood working machinery.

The NRRI research program has reduced this new aspen furniture making technique to practice with a non-conventional stool. This stool does not have vertical legs but rather has two diagonal struts running from the top frame to the bottom frame. The joints between the struts and the top and bottom frames are areas of high stress concentration. Using four 3/8-inch ply laminated construction the stool has one and a half-inch round parts. But the joints under stress are effectively three inch wide mortise and tenon joints. The stool has been found to withstand a 2,000 pound load level safely.

Work at NRRI is continuing on innovative aspen furniture making techniques. Presently we are working on a RTA upholstered chair design that can be used as a chair, or combined into a sectional couch or conventional couch. We welcome the furniture making industry to join us in the further development of this aspen furniture making technology.

FINISHING FURNITURE AND CABINET COMPONENTS

Another challenge requiring solution is to define techniques and technologies to factory finish aspen. We plan on finishing large edge glued panel products to show manufacturers, but the alternate desired result will be to create a business which manufactures and markets completely machined and pre-finished components. Even though we would like to see smaller furniture manufacturing firms use these components, the market development will be targeted to large OEM accounts as mid dollar product line options. We do not want them to use the aspen lumber, but rather we want to convince them to specify finished products and to convince them that they cannot afford to learn all that is necessary to use aspen. The marketing goal is for them to buy specific components from regional manufacturers who have developed the specialized knowledge to fully process these components.

Our efforts are concentrating on flat line finishing equipment and the use of a ultra-violet photoactive catalyst to produce the following finishes:

1. A high-gloss wet look.
2. Stained, sealed, and top coating.
3. Oil-hand rubbed.

These pre-finished products are the back-bone of our market development projects. We try to make sure these products catch the eye of the product manager. After developing and showing samples we plan to discuss the availability and price points of aspen versus other products that are currently the mainstream of furniture and cabinet making (i.e., red oak). It is difficult to break old patterns for use, but this approach appears to be our best chance for increasing the amount used and range of uses for aspen. So far one major manufacturer is seriously considering aspen for a new suite of furniture. This manufacturer has a new flat line finishing system which will paint the aspen with a wet look finish. Only time will tell if this industrial development project will be successful but we believe that furniture and cabinets made from an all U.S. hardwoods at a price point equivalent to off shore products will find its place in the market.

OPPORTUNITIES FOR ORGANOSOLV PULPING OF ASPEN

Jairo H. Lora[1]

ABSTRACT.--Organosolv pulping processes offer a lower-capital-cost, environmentally friendly alternative to conventional kraft pulping. Aspen is perhaps the species best suited to this type of processes. The ALCELL® process is an organosolv pulping process that has been tested extensively at the pilot plant level. This process recently advanced to demonstration in a large scale. High quality pulp and useful byproducts can be obtained from aspen by this process. Aspen pulping by the ALCELL® technology is a technically and economically feasible approach to fiber production.

INTRODUCTION

Organosolv pulping is a method of producing bleachable chemical pulp in which organic solvents such as alcohol are used instead of sulfur containing chemicals. The decade of the 1980s has seen a tremendous increase in interest on organosolv pulping processes which have advanced rapidly from the laboratory bench (where they were for many years) to the pilot plant and beyond. This increased appeal is a consequence of the lower environmental impact and lower capital cost of organosolv processes compared with conventional kraft and sulfite pulping.

The chemical characteristics of aspen make this wood an extremely suitable species for organosolv pulping. Its content of lignin (the material that holds the fibers together in wood) is among the lowest of all North American woods. Furthermore, the aspen lignin is more easily fragmented and solubilized under the conditions used in organosolv pulping. Therefore lignin removal and fiber liberation are relatively easy. These characteristics have made aspen one of the favorite raw materials for researchers developing and evaluating different approaches to organosolv pulping.

The ALCELL® process is the organosolv process that is close to commercialization in North America. Aspen has been used widely in the development of this technology. In this paper the application of the ALCELL® process to aspen is discussed.

DESCRIPTION OF THE ALCELL® PROCESS

The ALCELL® process is a patented technology (Diebold et al. 1978, Lora et al. 1988) that has been under development for several years. It is perhaps the simplest approach to organosolv pulping. Considerable attention has been paid not only to investigating pulping conditions, but also to optimizing solvent recovery and byproducts handling. The solvent in this process is typically an alcohol-water solution containing about 50 percent alcohol. When pulping most hardwood species, a catalyst is not required since enough acidity is generated from wood to effectively accelerate the delignification.

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The process has been described in the literature (Lora et al. 1985) and is schematically shown in Figure 1. In the Extraction Section wood chips are initially loaded into an extractor. After preheating with steam the chips are extracted in three stages with countercurrent flow of solvent at around 190-200°C. At the end of the third extraction the relatively clean solvent remaining in contact with the pulp is drained, the extractor is vented and then steam stripped until only trace amounts of alcohol remain. The pulp is discharged from the extractor, screened and sent to the bleach plant.

While the extraction section is batch, solvent and byproducts are recovered continuously. In the Lignin Recovery Section the black liquor obtained in the Extraction Section is flashed, and then diluted to precipitate the lignin. The lignin is recovered by settling, centrifugation and drying. The remaining solution contains alcohol, water and dissolved wood sugars. This stream is fed to the Alcohol Recovery Section, where a distillation tower recovers alcohol for re-use in the process. The stillage from the tower contains the wood sugars, which can be concentrated and spray dried, if desired.

Compared to the kraft process, the simplified ALCELL® process recovery system eliminates the brownstock washer, the recovery furnace, causticizing operations, and calcining operations, and replaces them with a conventional boiler, a centrifuge and a distillation tower.

ASPEN ALCELL® PULP PROPERTIES

Aspen ALCELL® pulps are obtained in yields one or two percentage points higher than aspen kraft pulps. As other hardwood ALCELL® pulps, they are characterized by their easy bleachability. As shown in Table 1 when kraft and ALCELL® pulps with similar amounts of residual lignin were bleached by seven different sequences, ALCELL® pulps consistently resulted in brighter pulps in fewer stages with lower chemical consumption (Lora et al. 1985). ALCELL® pulps are also effectively bleached by sequences that include oxygen stages.

Aspen ALCELL® pulps produced at the pilot plant scale have shown their equivalence to other bleached hardwood chemical pulps for papermaking in a variety of tests. As shown in Figure 2, aspen ALCELL® pulps have better strength than commercial aspen kraft pulps. Because of their strength, optical and surface properties, ALCELL® pulps are well suited for writing and printing paper grades as well as for tissue and dissolving pulp applications.

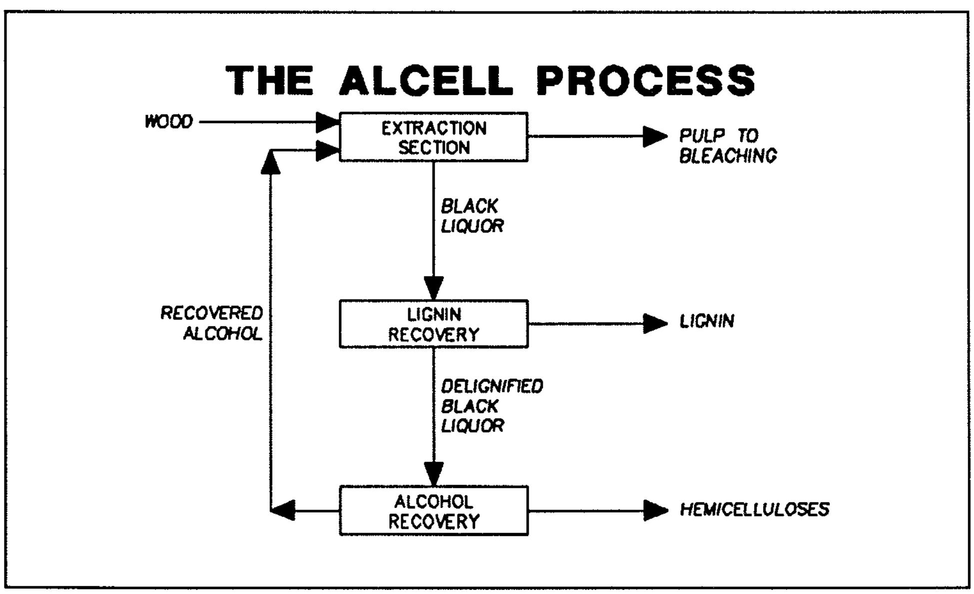

Figure 1.--The Alcell Process.

ASPEN ALCELL® LIGNIN

ALCELL® lignin is a material that resembles quite closely the lignin as it exists in the tree. Unlike lignins obtained from the kraft and sulfite processes, ALCELL® lignins do not contain chemically bound sulfur. ALCELL® lignins are biodegradable and undergo thermal softening at about 140°C. ALCELL® lignin is water insoluble under neutral or acid conditions but soluble in alkaline solutions and in certain organic solvents. It reacts with a number of organic chemicals used in the manufacture of resins and plastics, such as formaldehyde and propylene oxide.

Because of their chemical phenolic nature, ALCELL® lignin has been proposed as a substitute for phenol-formaldehyde (PF) resins. These resins are widely used as adhesives for wood composites and fiberglass insulation and as components of molding compounds, friction materials, foundry core binders and other applications.

Table 1.--Bleached pulp brightness (GE brightness).

Bleach Sequence	Kraft	ALCELL®
CEH	75.6 - 78.8	81.6 - 85.5
CEHD	86.0 - 87.0	87.0 - 90.0
CED	83.8 - 85.5	86.5 - 88.5
CEDED	87.5 - 89.0	89.0 - 90.5
C_DED	82.2 - 86.0	88.0 - 89.5
C_DEDED	87.0 - 88.0	87.8 - 90.2
DED	85.0 - 87.8	86.5 - 89.2

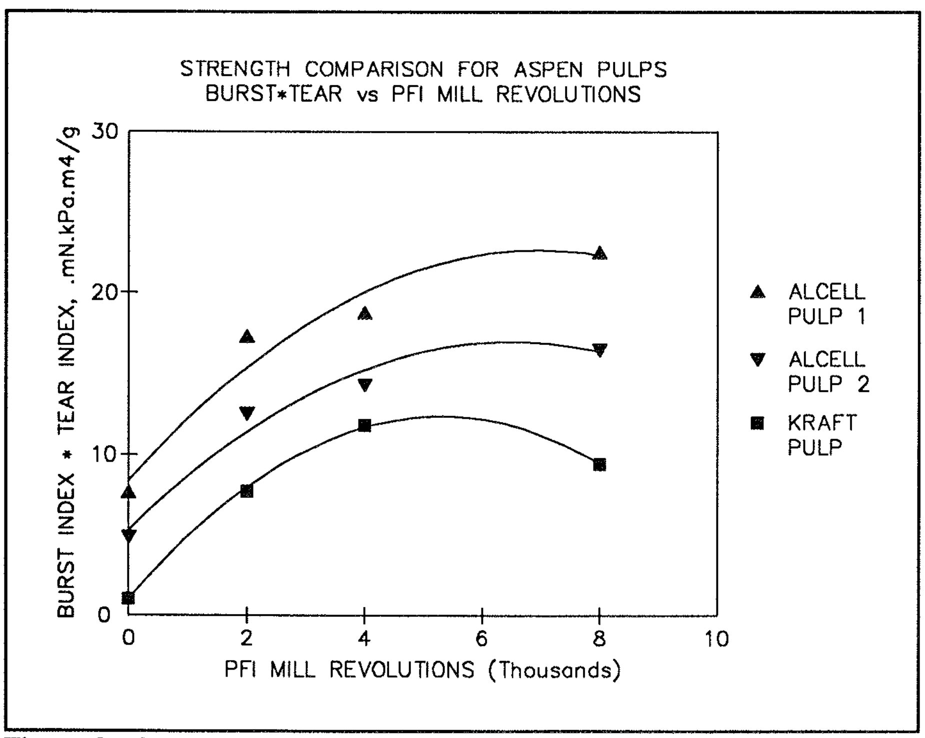

Figure 2.--Strength comparison for aspen pulps.

Most evaluations of ALCELL® lignin as a PF resin substitute have been aimed at the binding of structural wood panels such as waferboard. Earlier laboratory work has indicated the feasibility of replacing about 30 percent of the resin by ALCELL® lignin without deterioration of the board properties (Lora et al. 1989). These results have been confirmed in pilot trials in which 4 x 8-feet oriented strand boards were manufactured using ALCELL® lignin as direct partial replacement of the powder PF resin used in the core (Wu et al. 1989). Boards obtained in these trials were as good as or better than the controls when the level of substitution was 30 percent.

The reactivity of ALCELL® lignin has been used to incorporate it as a component of engineering plastics. An example of this is the use of ALCELL® lignin reacted with propylene oxide in the manufacture of flame retardant foams (Glasser and Leitheiser, 1984).

ASPEN ALCELL® HEMICELLULOSES

The other major byproduct of the process is the hemicellulose stream. In the case of aspen, the largest single component of this stream is a wood sugar called xylose. This can be used for the manufacture of the sweetener xylitol and of the important chemical intermediate furfural. The hemicellulose stream can also be fermented to produce Torula yeast (a food additive), or solvents such as acetone, butanol, 2,3 butanediol, isopropyl alcohol and (although at low concentration) ethanol. Alternatively this stream can be used as animal feed or as a boiler fuel.

CURRENT STATUS

After extensive testing at the pilot plant level the ALCELL® process has started undergoing further development in a larger scale plant located in New Brunswick, Canada. This plant can process batches of wood of about 20 tons (green). It includes complete solvent and byproduct recovery systems as well as pulp processing equipment. This plant started up in the spring of 1989 and has been using aspen as a raw material. The plant has demonstrated that it is possible to produce pulp and byproducts in a large scale by using the ALCELL® process. Current efforts are aimed at process optimization and further research and development.

CONCLUDING REMARKS

It appears that the time is near for this technology to be practiced industrially. The large anticipated demand for paper combined with the environmental and capital cost pressures that conventional chemical pulping processes are facing, could result in a shortage of high quality, high brightness pulps in the near future. The suitability of aspen for the ALCELL® process opens up tremendous opportunities for alleviating fiber shortages in an environmentally friendly manner with reasonable capital expenditures. Since the ALCELL® process is adaptable to small scale, it is conceivable to use it to:

1. Integrate pulp production with paper manufacture.

2. Refurbish sulfite mills that have been closed for environmental and/or economical reasons.

3. Add incremental capacity to kraft mills, especially to those that have bottlenecks in their recovery process.

Furthermore, the utilization of the byproducts from the ALCELL® process results in product diversification which will make a substantial impact on profitability and financial stability.

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PAPER BIRCH AS A CORE MATERIAL FOR ASPEN ORIENTED STRANDBOARD AND WAFERBOARD

Roland O. Gertjejansen, David C. Ritter, Bruce A. Popowitz, and Yong Chen[1]

ABSTRACT.--Thin paper birch strands and wafers, when used for the cores (33 percent by weight) of laboratory PF bonded aspen oriented strandboards (OSB) and waferboards (WB), resulted in properties that were equal to or better than those of all-aspen OSBs and WBs when compared over a density range of 37-43 PCF. Properties evaluated were internal bond (IB), moduli of elasticity and rupture (MOR), and, after a 2-hour boil bond durability test, thickness swelling (TS), linear expansion, and loss of MOR. Thick birch core geometries generally had deleterious effects on the critical core properties of IB and TS.

INTRODUCTION

The overall goal of an on-going project in the Department of Forest Products is to increase the use of underutilized Lake States hardwoods for wood base structural composite panels. The specific objective of this study was to determine if paper birch (Betula papyrifera), an underutilized hardwood, could be used as the core material for aspen oriented strandboard (OSB) and waferboards (WB). The potential benefits of utilizing paper birch as a core material in OSB and WB include reduced raw material costs for the manufacturer, greater raw material flexibility for the manufacturer, greater flexibility for the forest manager, and increased profits for the woodland owner.

PROCEDURE

Laboratory aspen OSBs and WBs, each made with four different paper birch core strand/wafer geometries (33 percent by weight), were compared to all-aspen boards over a density range of 37 to 43 PCF. All boards were bonded with phenol formaldehyde (PF) resin. Resin spreads on all strands and wafers were constant and equal to those obtained with commercial aspen strands and wafers at 5.0 percent liquid PF solids for strands and 2.2 percent powder PF solids for wafers. The strand and wafer dimensions are in Table 1 and manufacturing parameters are in Table 2.

Standard mechanical properties evaluated were internal bond strength (IB) and moduli of rupture (MOR) and elasticity (MOE). In addition, a 2-hour boil bond durability test was used to determine linear expansion (LE), total (TS) and irreversible (ITS) thickness swellings, and loss of MOR and MOE.

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Table 1.--Furnish geometry.

Furnish Type	Target Dimensions (inches) OSB	WB
Face, Commercial Aspen	0.030 x 0.33 x 2.25	0.036 x 1.50 x 3.0
Core, Paper Birch Thick-Narrow	0.040 x 0.25 x 3.00	0.036 x 0.50 x 3.0
Core, Paper Birch Thick-Wide	0.040 x 0.70 x 3.00	0.036 x 2.00 x 3.0
Core, Paper Birch Thin-Narrow	0.020 x 0.25 x 3.00	0.020 x 0.50 x 3.0
Core, Paper Birch Thin-Wide	0.020 x 0.70 x 3.00	0.020 x 2.00 x 3.0
Core, Commercial Aspen	0.030 x 0.33 x 2.25	0.036 x 1.50 x 3.0

Table 2.--Manufacturing parameters for experimental panels.

Parameter	OSB	WB
Face Material	Commercial Aspen Strands	Commercial Aspen Wafers
Core Material	Paper Birch	Paper Birch
% Core Material	33	33
% Face Material	67	67
Furnish Moisture Content	3%	3%
Target Densities (PCF)	37, 40, 43	37, 40, 43
Resin Spread (lb/1000 ft^2 surface area)	Face - 1.3 Core - 1.4	Face - .99 Core - .99
Resin Type	Liquid PF	Powder PF
Wax Content (Emulsion)	1% Solids	1% Solids
Press Cycle (Minutes)		
Time To Stops	1.00	1.00
Time At Stops	6.00	5.50
Decompression Time	0.50	0.75
Press Temperature (°F)	400	400

RESULTS

The results of this study are in Table 3. Generally speaking, thin birch strands and wafers, particularly the thin-wide, resulted in OSB and WB properties that were equal to or better than those of the all-aspen OSB and WB. More specifically, for the critical core properties of IB, TS, and ITS, the thin-wide strands and wafers resulted in panels that were superior to the all-aspen OSB and WB.

The thick strand and wafer geometries generally had deleterious effects on IB, TS, and ITS. Although the various core geometries should have had little effect on MOR and MOE, the thick-wide geometries did cause some MOR and MOE reductions in both OSB and WB. The thin birch geometries resulted in MORs and MOEs statistically equal to those of the all-aspen OSB and WB.

MORs and MOEs after the 2-hour boil bond durability test generally were not affected by core type except that the MOR of the thick-wide OSB was statistically lower than the other four OSB types. LEs after the boil test were the same for four of the five WBs; the thick-wide birch core wafers resulted in a statistically higher LE. LEs of the four OSB birch core types were approximately the same but somewhat greater than that of the all-aspen OSB. Cross-LEs were statistically greater for the OSBs made with the two thick birch strands.

SUMMARY

The excellent performance of WBs and OSBs with cores made from thin-wide paper birch strands and wafers suggests that a feasible design for a two-species three-layer OSB or WB would be aspen strands/wafers for the faces and thin-wide birch strands/wafers for the cores. This design, if adopted by OSB and WB manufacturers, would help reduce the aspen shortfall predicted for the year 2000.

Research on this project continues. We will be using the best paper birch core geometry, which is the thin-wide, and then will determine minimum acceptable resin spreads, maximum thicknesses of "thin" strands/wafers, maximum amounts of birch for the cores, advantages if any of mixing aspen with birch for the cores, and advantages if any to be gained by manipulating the press cycle and mat moisture content.

Table 3.--Predicted mean values for selected properties of laboratory oriented strandboards (OSB) and waferboards (WB) at 40 PCF density.

Core Type	Modulus of Rupture (psi)				Modulus of Elasticity (1,000 psi)				Internal Bond (psi)		Thickness Swelling (percent)			
	OSB		WB		OSB		WB		OSB	WB	OSB		WB	
	non-aged	aged[1]	non-aged	aged[1]	non-aged	aged[1]	non-aged	aged[1]			Total	Irrev.	Total	Irrev.
thick-narrow	5880	2930	3850	2180	1050	551	653	358	57	83	34	22	38	25
thick-wide	4830	2850	3930	2380	944	539	611	385	75	74	30	18	35	23
thin-narrow	5200	2700	4430	2200	964	508	610	370	95	84	28	16	34	22
thin-wide	5680	2820	4150	2070	1020	538	613	326	92	91	26	14	28	16
commercial aspen	5960	3340	4210	2470	1030	621	613	380	83	80	31	18	33	21

[1]Tested wet after a 2-hour boil bond durability test.

DEVELOPING TISSUE CULTURE SYSTEMS FOR INCREASING THE DISEASE RESISTANCE OF ASPEN

M. Ostry, B. Bucciarelli, S. Sain, W.P. Hackett, and N.A. Anderson[1]

ABSTRACT.--In vitro techniques are being developed for clonal propagation of selected clones of superior aspen and hybrid poplars. We have increased the efficiency of rooting tissue culture-derived aspen and are developing rapid screening systems for the identification and recovery of aspen that are resistant to Hypoxylon canker.

Recent forecasts indicate that demand for aspen pulpwood and particleboard will continue to increase (Blyth and Smith 1989). Some projections point to a shortage of aspen in the next 20—30 years in the Lake States due to the age structure of our existing stands. Plans for planting and managing aspen more intensively have been mentioned in response to the expected shortfall. Planting genetically improved clones of aspen that grow fast and resist disease can increase the supply of quality aspen in the near future. However, efficient, economical systems for screening trees for disease resistance and clonally propagating selected genotypes are needed.

Tree improvement involves identifying, recovering, and multiplying unique, useful gene combinations that provide the desired growth, quality, and stress resistance traits. The long generation time of trees, lack of knowledge about juvenile-mature trait correlations, and difficulty in obtaining the transfer and expression of desirable genes at high frequencies, seriously limit the use of the classical selection, breeding, and testing methods for forest trees. Manipulation of trees using various cell and tissue culture techniques provides a great potential advantage in tree improvement (Haissig et al. 1987).

Efficient in vitro regeneration of most commercially important forest trees is presently difficult or impossible. One exception has been the numerous successful in vitro techniques developed for members of the genus _Populus_ (Ahuja 1987). The first complete plantlet to be regenerated from unorganized callus of a woody plant species and established in the field was obtained from trembling aspen (_Populus tremuloides_ Michx.) (Winton 1970).

Our objectives are to develop rapid methods of identifying aspens resistant to Hypoxylon canker caused by _Hypoxylon mammatum_ (Wahl.) Mill. and to develop in vitro systems for the recovery and clonal propagation of improved aspen genotypes.

CLONAL PROPAGATION

The conventional method of propagating selected aspen genotypes using root suckers in a greenhouse is labor- and time-intensive and inefficient in providing large numbers of plants. Trembling aspen, like most members of the Leuce section, does not root easily from stem cuttings. Previous research has

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demonstrated that in-vitro propagation of aspen is feasible; however, successful rooting of microshoots was variable (Wolter 1968, Christie 1978, Chalupa 1979, 1981, Ahuja 1983, Barocka et al. 1985, Noh and Minocha 1986).

We have developed techniques that have increased the efficiency of in vitro and in vivo rooting of tissue culture-derived shoots of a selected clone of trembling aspen. Roots were collected from a 76-yr-old ramet of a superior disease-resistant clone of aspen growing in northern Minnesota. Stock plants were produced by excising suckers from these roots and rooting them in the greenhouse.

Nodal segments (Rutledge and Douglas 1988) from actively growing shoots were surface sterilized and placed on WPM + 12 mM calcium gluconate + 20 mg l^{-1} adenine sulfate + 0.5 mg l^{-1} BAP (Christie 1978, Lloyd and McCown 1980, Ahuja 1983) and transferred every 7-10 days onto fresh medium under 16-hr photoperiods at 25°C in a growth chamber. After 4 months, 30-60 microshoots per nodal segment had formed.

To induce rooting in vitro, elongating microshoots were excised and transferred to WPM minus myoinositol and glycine + 12 mM calcium gluconate + 0.5 mg l^{-1} IBA and 0.1 mg l^{-1} NAA. Microshoots then were placed in growth chambers and grown at 25°C for 7 days in the dark followed by 7 days under a 16-hr photoperiod. After roots had formed, microshoots were transferred to a (3:1) vermiculite:perlite mixture and then placed in a growth chamber under 24 hrs continuous light at 25°C with frequent misting to maintain high humidity. Plants were transferred to the greenhouse after 2-3 weeks. Using this technique, 92 percent of the cultured microshoots rooted.

In vivo rooting of microshoots was accomplished by giving them a 12-hr pulse treatment in 50 or 100 mg l^{-1} IBA. The pulsed shoots were transferred to vermiculite:perlite mixture and grown in a growth chamber under 24 hrs continuous light at 25°C with frequent misting. After 4 weeks 94-100 percent of the shoots formed roots and were transferred to the greenhouse. These plants are now being field-tested in Minnesota and Wisconsin for growth and disease resistance.

Using these techniques, we have also cultured and rooted several other aspen clones with varying degrees of success. Such clonal differences were also noted by Ahuja (1983) and indicate that methods developed for one genotype may have to be modified to obtain maximum efficiency for other genotypes.

Zeldin and McCown (1986) demonstrated that excised roots of poplars can be grown in vitro and shoots can be differentiated from these cultured roots. We have successfully regenerated and transferred plants of hybrid poplar and aspen clones to soil in the greenhouse from excised root cultures. Sterile excised roots from shoot cultures were placed in liquid WPM supplemented with NAA, placed on a roller culture apparatus in the dark, and rolled at low RPM. Large masses of roots developed within 1-2 months. Shoots were induced by placing segments of roots onto solid WPM supplemented with BA. Thus far, 5-10 shoots per cm segment of aspen root have been produced. Preliminary results with aspen root cultures thus far are encouraging.

We have regenerated shoots from root cultures of 11 different hybrid poplar clones. Poplar clones vary in their regeneration response with some clones producing 10 or more shoots per cm root segment. Clonal propagation via in vitro root culture is a promising system for efficiently obtaining planting stock of superior aspen and hybrid poplars.

SCREENING FOR HYPOXYLON CANKER RESISTANCE

Recently, tissue culture systems have been developed to screen aspen for resistance to infection by _H. mammatum_. Einspahr and Wann (1985) screened aspen plantlets for resistance to _H. mammatum_ toxin by regenerating plantlets from cotyledon explants on toxin-containing media. Valentine et al.

(1988) screened clones of P. tremuloides for resistance to H. mammatum. Callus cultures were exposed to fungal culture filtrates and tissue-cultured plantlets were inoculated with ascospores of the fungus. There is evidence that clones resistant to Hypoxylon canker have the ability to rapidly produce callus which closes wounds that could otherwise be invaded by the fungus (Ostry and Anderson 1983). This rapid callus development may be responsible for limiting canker expansion. We are evaluating in vitro systems to assess the ability of aspen clones to produce callus as an indicator of resistance to infection by H. mammatum.

FUTURE APPLICATIONS

Applying cell and tissue culture techniques to aspen offers promise for clonal propagation and screening for disease resistance. Tissue culture may also be used to produce useful somaclonal variation (Larkin and Scowcroft 1981). Somatic variation in the resistance of hybrid poplars to the pathogen Septoria musiva Peck was recently identified and recovered in hybrid poplars derived from tissue culture (Ostry and Skilling 1988). Some of these plants have remained disease-free after 3 years in the field. Similar somaclonal selection techniques could be used for developing aspen with resistance to Hypoxylon canker once reliable bioassay techniques are developed.

Many biotechnological strategies using tissue culture for tree improvement have been applied to poplars (Haissig 1986). Although the practical use of these techniques still need demonstration, the success of several model systems illustrates their potential to complement traditional tree breeding and reduce the time required to develop desirable traits in forest trees.

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WHAT IS IMPORTANT TO BLACK BEARS IN THE LAKE STATES?

Lynn L. Rogers, Gregory A. Wilker, and Sally S. Scott[1]

ABSTRACT.--Black bear habitat studies in Minnesota, Wisconsin, and Michigan incorporated close observation of wild, researcher-habituated black bears in Minnesota and analysis of >500 droppings from throughout the region. Important habitat components include: mature oak stands (acorns), mature black cherry stands (cherries), forest openings (other wild fruits, legumes), ash and alder swamps (bluejoint grass, jewelweed), marshes (wild calla), rotting logs (ant pupae), and large white pine or hemlock trees (refuges, especially for spring cubs). Heavily used forest openings occur in overmature aspen stands that are breaking up. These stands provide numerous non-sodded openings containing wild fruits, legumes, and ant colonies.

Researchers are determining habitat use of bears by examining droppings from throughout the Great Lakes Region and by watching wild bears that have learned to accept observers. Recorded data include all activities and each bite of each food in each habitat.

Mothers with cubs spend more than 95 percent of their time in April and May within 100 yards of white pines or hemlocks larger than 20 inches DBH. The bark of these trees is especially safe for climbing by small cubs. Preferred spring habitats have at least one of these refuge trees per six acres.

Ash swamps and other riparian areas are important feeding areas. Lowland grasses are eaten in spring. Wild calla and jewelweed are eaten from June through September. Riparian habitats with adjacent refuge trees are preferred.

Important upland plants include peavine, clover, wild lettuce, and dandelions. These are found primarily in forest openings and along roadsides.

Over half the diet in June, depending upon availability, may be ant pupae from down the dead woody material. Major ant-feeding sites are overmature forests that are breaking up and clearcuts with rotting logs.

Major foods of mid- and late summer are wild fruit and hazelnuts unless these crops are destroyed by frost or drought. Forest openings, timber stands with fewer than 300 trees per acre, and black cherry stands are major production areas for most of these species.

Acorns significantly influence black bear reproductive success. In some areas acorns are the only hard mast available after September. Bears commonly travel more than 20 miles to mature oak stands in fall. Where scarce, oak stands merit protection for their wildlife values. Beech nuts are also important in some areas.

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Bears have few den requirements in northern forests where winter flooding is uncommon and where people or domestic dogs are unlikely to disturb natal dens. Many bears simply make nests on the ground surface. Winter survival is over 99 percent.

Household garbage, campers' food, and farmers' crops attract bears and lead to many deaths. Over 95 percent of black bear deaths (except cubs) are from gunshot. Sustained yield hunting does not threaten bear populations, but unregulated killing can eliminate them.

Of primary importance to black bear population survival are extensive forests where bears can avoid unregulated, human-caused mortality and where mothers can raise cubs without excessive disturbance.

QUANTIFYING THE PHYSICAL ASPECTS AND IMPACT OF FIRE IN ASPEN ECOSYSTEMS

Rodney W. Sando and Martin E. Alexander[1]

ABSTRACT.--This paper very briefly summarizes the results of a study dealing with the characteristics of fire behavior and the biological effects of fire on woody vegetation in six aspen-northern hardwood stands. Burning conditions were described in terms of the Canadian system of forest fire danger rating. The response of trees and shrubs was surveyed at the end of the first growing season following fire. A prescription for prescribed burning to improve wildlife habitat is presented.

Although trembling aspen is considered a "fire type" (i.e., it follows or is otherwise dependent on fire) and a wealth of fire effects literature exists, surprising little empirical fire behavior data is available. In 1968 and 1970, six experimental prescribed fires were carried out within pure trembling aspen and mixed hardwood stands in Minnesota and Wisconsin (Sando 1972). These fires were initially conducted in order to formulate prescribed burning guidelines for wildlife habitat improvement (Table 1); however, they have also proved valuable in the development of a guide to predicting wildfire behavior in the context of the Canadian Forest Fire Danger Rating System (Alexander and Sando 1989).

The six fires were conducted in spring or late fall (i.e., leafless stage) when the available surface fuel loads averaged 2.5 tonnes per hectare (1.1 tons per acre). The burning conditions were rated as high to extreme by the Canadian Forest Fire Weather Index (FWI) System. The head fire rates of spread (ROS) varied from 1.5 to 8.8 metres per minute (5-29 feet per minute) and were highly correlated with the Initial Spread Index (ISI) component of the FWI System ($r = 0.91$). The quantitative information on fire behavior provided by this study has been combined with other similar experimental data from eastern and northern North America (e.g., Alexander 1982, Quintilio et al. 1989) and selected wildfire observations for use in derivation of an ISI-ROS relationship for Fuel Type D-1 (leafless aspen) in the Canadian Forest Fire Behavior Prediction System (Alexander et al. 1984).

Frontal fire intensities ranged from 115 to 672 kilowatts per metre (33-194 Btu per second per foot). Extensive mortality was observed in deciduous trees less than about 8 centimetres (3 inches) diameter at breast height (DBH), but overstory stems greater than about 15 centimetres (6 inches) DBH were seldom affected. Most shrub species were readily killed by fire but quickly resprouted. The total number of woody understory stems often increased following the fires.

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Table 1.--Recommended burning prescriptions for applying prescribed fire in aspen-northern hardwood stands not subjected to cutting in order to manage for wildlife habitat improvement objectives (adapted from Sando 1972).

Prescription Element[1]	Effective Prescription[2]	Optimum Prescription
Dry-bulb Temperature	> 15.5°C (60°F)	21-27°C (70-80°F)
Relative Humidity	≤ 35%	20-30%
10-m Open Wind 20-ft Open Wind	18-28 km/h 10-15 mph	18-28 km/h 10-15 mph
Days Since Rain	≥ 4	≥ 5
Time of Year Spring	Spring	

[1]Both the Canadian and U.S. fire weather/danger standards for wind speed measurement are given.
[2]Based on the range of conditions studied.

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SELECTION OF HYBRID POPLAR CLONES UNDER VARYING MOISTURE REGIMES: PRELIMINARY RESULTS

T.A. Walsh, T.E. Burk, and J.G. Isebrands[1]

ABSTRACT.--The success of hybrid poplar planting programs depend on the selection of clones with desirable growth properties, that are matched to specific environmental conditions. Traditionally, tree geneticists have relied on early height growth as a good indicator of rotation age volume production. Our experience with intensively cultured hybrid poplar suggests that this assumption may be questionable. A mixed planting of 36 Populus clones of three species was analyzed after three years growth. A procedure was derived that allowed construction of selection functions based on multiple morphological and physiological traits. The selection functions were used to examine clonal differences and to explore relative rankings between clones. Preliminary results suggest that even simple selection functions are superior to early height growth for identifying hybrid poplar clones for volume production.

INTRODUCTION

In the future, forest managers hope to achieve rotation ages of 10 to 15 years for Populus grown under intensive culture in the north central United States. Presently, the economics of Popular breeding programs does not allow geneticists to select individuals on the basis of rotation age production. Although experience has shown that performance after five growing seasons is often indicative of performance at rotation age, even five years is too long an evaluation period. Ideally, traits that can be observed after two or three growing seasons that relate closely to five year fiber production are desired. When multiple traits can be identified, multivariate statistical methods may be useful in determining the combination of the traits most closely related to five year fiber production. Baker's (1986) recent work provides a summary of research on the development of selection indices for agronomic crops, while Zuuring (1975) gives examples of the application of selection indices to Populus clones.

The use of the genus Populus for intensively cultured forestry in the north central United States has been researched extensively for almost twenty years. A part of this work has dealt with quantifying morphological differences between clones and how the differences relate to cultural practices, developing strategies for determining differences between individuals in terms of photosynthetic potential, and identifying physiological characteristics indicative of water stress resistance. In this study we propose that previous knowledge be used to identify easily observed characteristics useful in selecting individuals for advancing a Populus breeding program. The specific objectives of this research are to identify and quantify early selection criteria for Populus breeding programs that are well correlated under varying moisture conditions with volume at rotation age, and to incorporate these characteristics into selection functions. Such functions can be used at a young age to select for parent as well as progeny clonal material.

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DATA

Preliminary measurements of phenological, morphological, and photosynthetic variables were initiated in 1986 (year of establishment--see next section). In 1987 a subset of the clones was selected for further research based on 1986 performance. In both 1987 and 1988, measurements were taken at monthly intervals during June, July, and August. Information was collected on a representative proleptic branch (i.e., branch formed from a bud that has overwintered) from the "upper" portion of each Height Growth Increment (HGI, height growth of a tree during a given year) and from the "lower" portion of each HGI. A representative sylleptic (i.e., branch formed from a bud that has not overwintered) was also sampled from the current terminal (current year's HGI).

The data set included three types of variables:

1. measured (directly measured tree attributes)
   - total tree height
   - tree basal diameter
   - number of branches
   - basal diameter and length of each HGI
   - number of leaves and leaf positions on the current terminal
   - leaf lengths (three representative leaves from the current terminal were measured)
   - measurements on representative branches:
   - length and diameter
   - number of secondary branches
   - angle of origin
   - vertical tip (horizontal distance from tip of branch to the stem)
   - vertical length (vertical distance from base of branch to point where vertical tip was measured on the stem)
   - number of leaves and leaf positions
   - leaf lengths (every fifth leaf was measured)

2. derived or estimated (calculations based on assumptions)
   - leaf area of the largest measured leaf on the current terminal
   - total leaf area of the tree
   - number of leaves on the tree
   - branch surface area
   - stem volume
   - total tree volume

3. transformed (functions of 1 and 2)
   - ratio of total height over basal diameter
   - the square of basal diameter times height
   - number of branches per unit length of stem
   - branch volume per unit of stem volume

Variables listed for types two and three represent a subset of the variables which were tested.

MATERIALS AND METHODS

The initial field study was planted at two meter spacing in 1986 at the US Forest Service Harshaw Experimental Farm near Rhinelander, Wisconsin. Twelve clones were planted for each of three species of Populus: balsamifera (B01-B12), deltoides (D01-D12), and trichocarpa (T01-T12). In each of the 12 plots the 36 clones were arranged at random. In order to assess clonal performance under varying moisture conditions, three irrigation treatments were randomly applied to the twelve plots:

1. no irrigation
2. irrigate when soil moisture tension = -1.5 bars
3. irrigate when soil moisture tension = -0.5 bars

There were four replications of each clone, irrigation combination available for study, of which we used two.

Of the 36 clones available, four clones per species were selected for examination in this study (Table 1). Data were analyzed as a completely randomized, split plot design with moisture regime representing the whole plot treatment and clone representing the subplot treatment. A univariate analysis of variance was performed on variables at each of the three measurement dates in a given year. The multivariate technique, canonical discriminant analysis (CDA), was also used to determine which variables might perform well in selection functions. Johnson and Wichern (1988) and Morrison (1976) provide detailed descriptions of the process of CDA (referred to as canonical correlation analysis in both references). CDA is a dimension reduction technique. It is equivalent to correlation analysis between the quantitative variables (e.g., total tree height, maximum leaf area, number of branches per unit length, etc.) and dummy variables coded from the class variables (e.g., clones). In other words, CDA helps to identify a subset of variables that describe the underlying relationships between class variables and quantitative variables. A linear combination of the variables that has the highest possible multiple correlation with the classes is identified using CDA and is called the first canonical variable. The second canonical variable is the linear combination uncorrelated with the first canonical variable that has the next highest multiple correlation with the classes. This process of generating canonical variates continues until one reaches the number of original variables or the number of classes minus one (whichever is smaller). The coefficients of the linear combinations are termed canonical coefficients. One can standardize the coefficients to have zero mean and variance of one. Standardizing the coefficients insures similarity of scale which is helpful for determining relative contributions of individual coefficients.

The first canonical correlation is at least as large as the multiple correlation between the classes and any of the original variables. If the variables have low within class correlations the canonical variable is not much greater than the largest multiple correlation. If the original variables have high within class correlations, the first canonical correlation can be large even if all the multiple correlations are small. Thus, the first canonical variable can show substantial differences among classes even if none of the original variables do.

Multivariate analyses of variance were run for groups of commensurable responses and standardized canonical variable coefficients were calculated for each group. In the present study, several desirable results were sought from the canonical discriminant analyses:

1. The first, or first and second, canonical variate(s) explain a large percentage of the variation between classes (e.g., clones).

2. The canonical correlation is significantly greater than zero (a likelihood ratio test p-value is an indicator of this), i.e., it explains a significant amount of variation between the classes.

3. The canonical variates are formed using interpretable coefficients. Standardized canonical coefficients were examined instead of the unstandardized coefficients. With standardized coefficients the relative contribution of a particular variable is directly proportional to its canonical coefficient.

The 1987 data were used to construct the selection functions, and the 1988 data were used to determine the ability of the functions to rank the clones in order of total tree volume production.

Table 1.--Origin of Populus balsamifera, P.trichocarpa, and P.deltoides clones.

Species	Clone #	Clonal Origin
balsamifera		
B01[1]	LU002	Thunder Bay, Ontario, Canada
B02	LU039	Kakaboka Falls, Ontario, Canada
B03	LU112	Central Patricia, Ontario, Canada
B04	LU151	Pickle Lake, Ontario, Canada
B05	LU205	Eagle River, Wisconsin
B06	LU235	Crandon, Wisconsin
B07[1]	LU253	Long Lake, Wisconsin
B08	LU258	Summit Lake, Wisconsin
B09	LU259	Pelican Lake, Wisconsin
B10[1]	LU264	Rhinelander, Wisconsin
B11	LU272	Lily, Wisconsin
B12[1]	LU273	Lily, Wisconsin
trichocarpa		
T01[1]	2-3-5	Clark Fork, Idaho
T02	3-2-4	Coeur D'Alene River, Idaho
T03	4-3-5	Uruqhart, Idaho
T04	4-4-4	Calder, Idaho
T05	4-6-4	Erlmo, Idaho
T06[1,2]	5-1-5	Myrtle, Idaho
T07	5-2-5	Peck, Idaho
T08[1]	0-6-1	Barriere, British Columbia
T09[1]	0-6-5	Barriere, British Columbia
T10	0-9-2	Lumby, British Columbia
T11	0-10-2	Vernon, British Columbia
T12	0-13-1	Merritt, British Columbia
deltoides		
D01[1]	41-3	Indiana
D02	41-6	Indiana
D03	44-4	Indiana
D04	264-4	Illinois
D05[1]	269-4	Illinois
D06	291-5	Illinois
D07[1]	170-3	Minnesota
D08	171-6	Minnesota
D09	175-2	Minnesota
D10	180-6	Minnesota
D11[1]	189-3	Minnesota
D12	192-4	Minnesota

[1]Indicates clones examined in this study.
[2]Clone T06 was eliminated from the study after 1987 due to severe damage by Septoria canker.

RESULTS AND DISCUSSION

ANALYSIS OF VARIANCE

Because multiple testing with univariate analyses of variance does not provide statistically valid results, univariate analyses of the aforementioned variables were examined for general trends and not for determination of specific significance levels. For both 1987 and 1988 clones were statistically different for most variables examined. Moisture regime effects were not significant in 1987, but they were apparent for several variables during the peak of the 1988 drought. July measurements of total height, maximum leaf area, and number of leaves showed the most potential as indicators of drought effects. In 1987, no moisture regime interactions were significant, but there were some indications of clone by moisture regime interactions in July of 1988. Specifically, estimated July volume variables showed a significant clone by moisture regime interaction. This suggests that clonal rankings of volume may change under different moisture conditions.

SELECTION FUNCTION DEVELOPMENT

Three types of selection functions were constructed based on 1987 morphological variables:

1. Functions based on a single variable as an index of potential volume production (e.g., August height, August D^2H).

2. Functions based on more than one easily measured variable and transformations of such variables (e.g., June and August total height, June and August total volume, August total height over diameter)--labeled simple functions.

3. Functions based on a combination of derived variables and transformed variables (e.g., June, July, and August branch surface area per cubic cm of total tree volume)--labeled complex functions.

Using the methods described previously a relatively small number of functions were developed. Given the methods of development and the relatively small number of functions developed, we are confident that our results are not an artifact of data mining.

Multivariate methods described earlier were used to calculate "scores" for function types 2 and 3 above. Each clone was ranked by its respective score. Rankings of total volume estimates at the end of the 1988 growing season were used to test the performance of the selection functions. Figure 1 illustrates the ability of 1987, end-of-year height to appropriately rank clones on the basis of 1988 end-of-year volume production. The x-variable indicates the clone. The y-variable was calculated by taking the clonal mean value of the variable of interest and then dividing each individual clonal value by the mean. Multiplying by 100 gave a percentage of the mean which allowed for comparison between graphs. The line connected by solid black diamonds (1988 volume production) is the reference line. The more closely the function line follows the general trend of the reference line, the more appropriate the function is for selecting clones based on volume production. Spearman's rank correlation coefficient (a measure of the degree of correspondence between rankings) provides a quantitative measure of the ability of these functions to rank the clones by 1988 end-of-season total volume. Judging from Figure 1, height at a young age is a poor indicator of future total tree volume; using height alone gives an underestimate of "good" performers and an overestimate of the "poor" ones. We believe the most critical clones to rank correctly are the "best" clones. There is a large difference in volume between the best and the fourth best clone (e.g., T08 has twice the estimated volume of D07). It should be noted that 1987 end-of-year height does not rank any of the four best clones correctly.

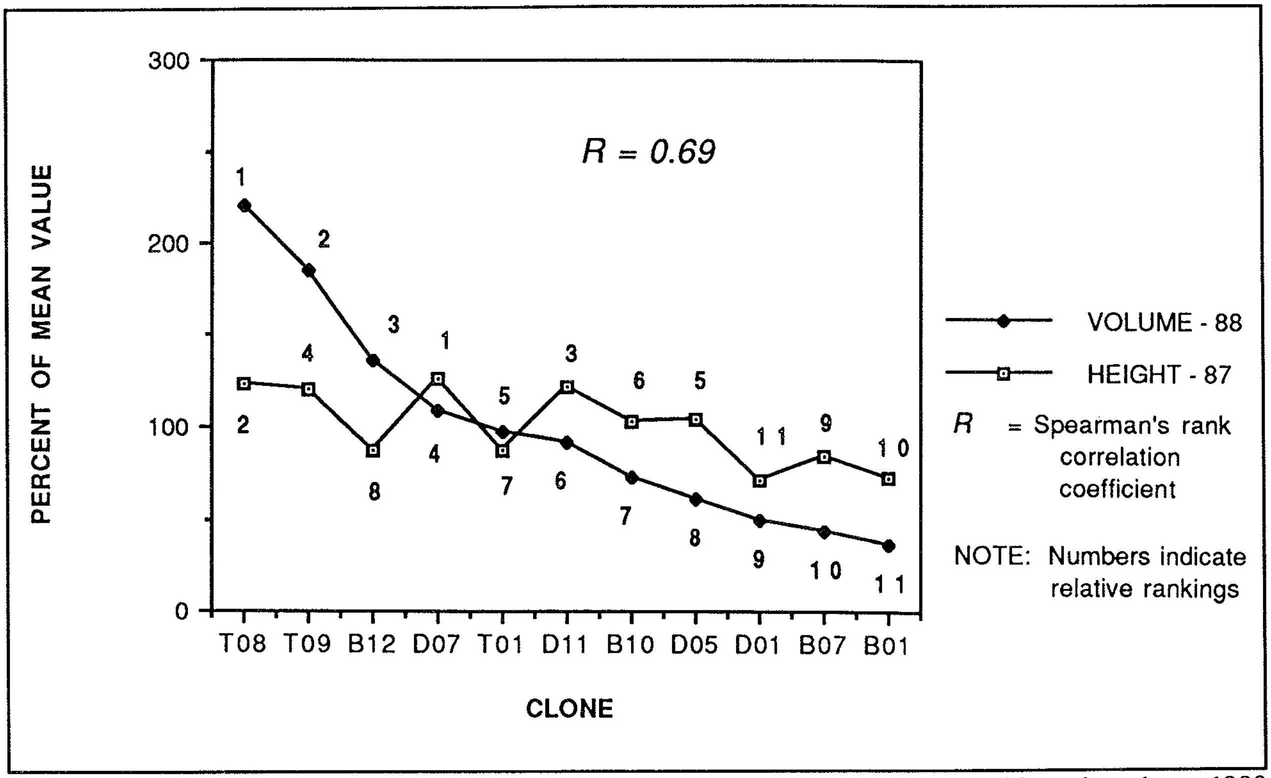

Figure 1.--Clonal rankings based on 1987 end-of-year height compared to rankings based on 1988 total tree (stem and branch) volume.

From Figure 2 one can see that D^2H performs somewhat better than height. However, D^2H does not rank any of the top four clones correctly.

Examples of the simple and the complex functions are found in Figures 3 and 4, respectively. Both the simple and the complex function rank three of the top four clones correctly. Both have a Spearman's correlation coefficient of greater than ninety percent. The simple and complex functions described here outperform typical methods of clonal selection (i.e., height and D^2H). Selection functions similar in composition to the simple function have the potential of providing a more sophisticated and reliable technique of selecting superior clones in genetics breeding programs. Since the variables in the complex function require more intensive measurements, the complex function will not be as practical for use in tree breeding programs. However, complex functions will be useful for answering questions concerning impact of pollution, acid rain, and ozone on trees.

Isebrands and Michael (1986) found that whole tree photosynthesis (integrated over the growing season) was closely related to biomass production in three Populus clones. Isebrands et al. (1988) found that early selection based on morphological and physiological traits could provide improvements in Populus biomass production. The addition of phenological and photosynthesis variables are being tested to determine if they aid in the predictive ability of the selection functions. Testing of these selection functions with volume data from four and five year old trees will aid in determining if the relationship between yield and these selection functions will hold through rotation.

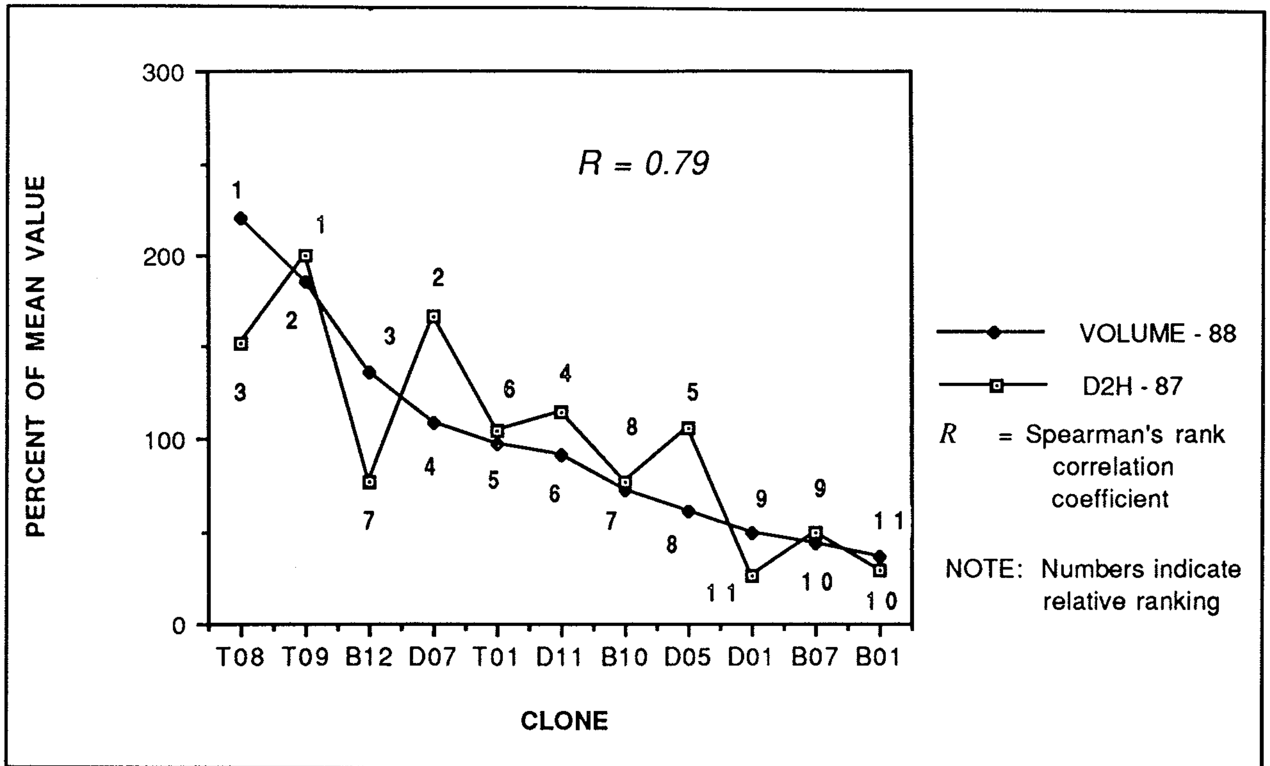

Figure 2.--Clonal rankings based on 1987 end-of-year D2H compared to rankings based on 1988 total tree (stem and branch) volume.

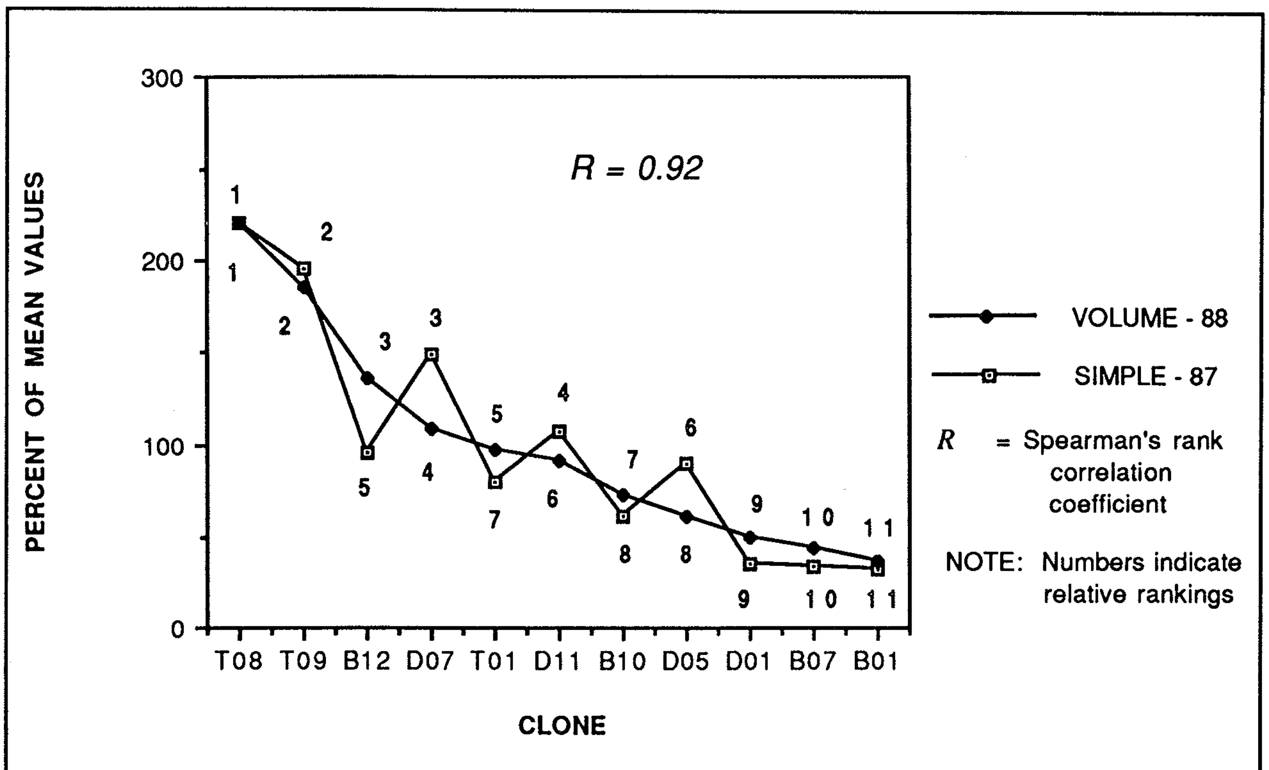

Figure 3.--Clonal rankings based on 1987 simple function compared to rankings based on 1988 total tree (stem and branch) volume.

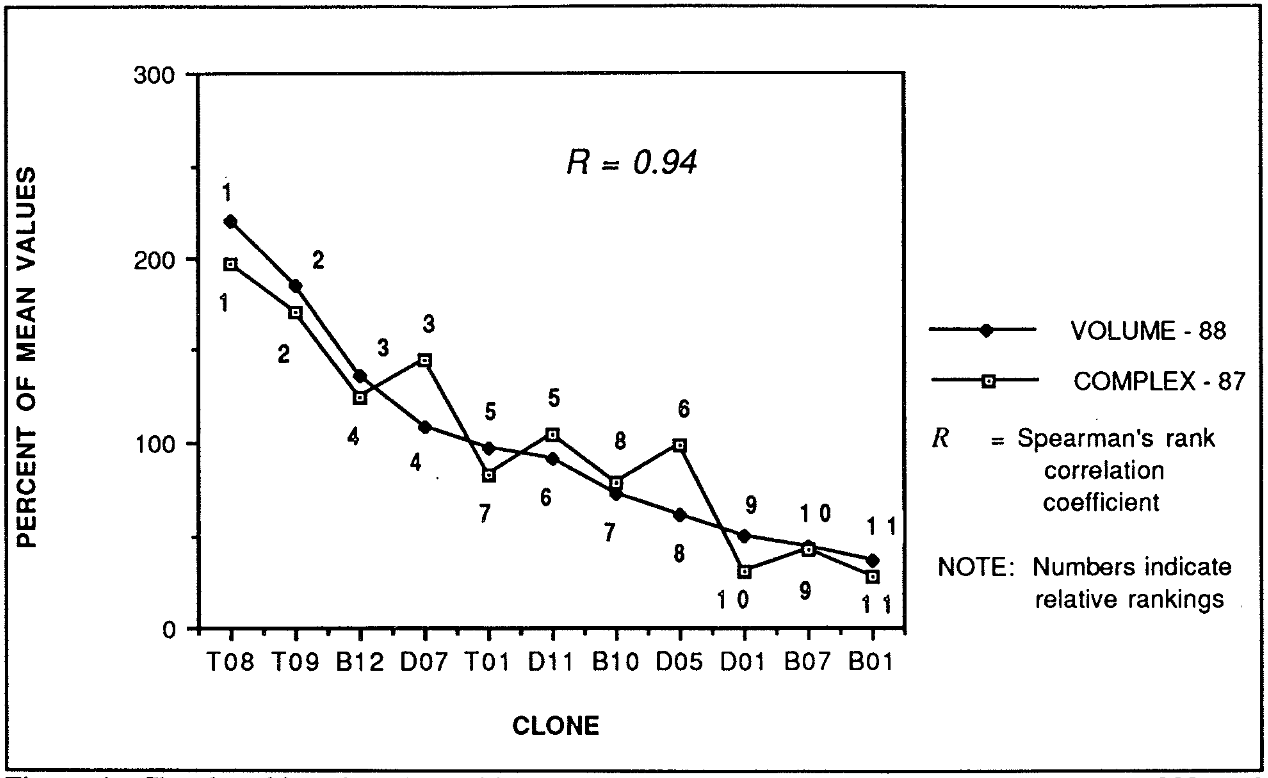

Figure 4.--Clonal rankings based on 1987 complex function compared to rankings based on 1988 total tree (stem and branch) volume.

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RECENT PROGRESS OF THE GREAT LAKES FOREST GROWTH AND YIELD COOPERATIVE

D.K. Walters and A.R. Ek[1]

ABSTRACT.-The Great Lakes Forest Growth and Yield Cooperative (GLFGYC) is designed to encourage the development of forest growth and yield information in the Great Lakes region of Canada and the United States. The primary objective of the cooperative is to foster the collection, pooling, and synthesis of such data within the region and to provide a strong data base for developing and refining forest growth and yield prediction methods. The cooperative also aims to identify priorities, provide direction, and encourage the development of new growth and yield models and the improvement of existing models. Although emphasis is on maximizing the utility of existing data, the GLFGYC is installing a number of permanent forest growth plots in the vicinity of weather stations. These plots will assist in monitoring the effect of changing climatic patterns, improving growth prediction, and understanding the impacts of acid deposition.

INTRODUCTION

The Great Lakes Forest Growth and Yield Cooperative arose from the need for accurate, localized and broadly useful forest growth and yield. Similar cooperatives have already been developed in other areas of the U.S. and Canada. The cooperative's establishment was made possible with a grant from the Legislative Commission on Minnesota Resources and support from existing projects of the University of Minnesota Agricultural Experiment Station, the Minnesota Department of Natural Resources, and the USDA Forest Service North Central Forest Experiment Station. The cooperative has attracted membership from six states and the Canadian province of Ontario in the Great Lakes Region.

JUSTIFICATION AND OBJECTIVES

The availability of long-term remeasured plot data describing forest growth and yield is fundamental to forest growth and yield prediction. Much data is already collected by a variety of organizations. The primary objective of the cooperative is to foster the collection, pooling, and synthesis of such data within the region to provide a strong data base for developing and refining forest growth and yield prediction methods. The cooperative also aims to identify priorities (see Table 1), provide direction, and encourage the development of new growth and yield models and the improvement of existing models. These objectives will be pursued from funds developed within and external to the cooperative.

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Table 1.--Important issues in forest growth and yield in the Great Lakes region as identified by the members of the GLFGYC in July, 1988.

Ranking of Importance	Issue/Concern
1	The development of procedures and guidelines for the installation of permanent plots.
2	The development of localized, empirical yield tables in the Great Lakes region, especially for young stands.
3	A vehicle for communicating information about growth and yield research and to enhance the availability of data for various studies.
4	Development of a system for cataloging, storing, and retrieving data sets available for growth and yield research projects.
5	Development/refinement of young stand growth and yield information and models.
6	Collection, screening, and cleaning of growth and yield data.
7	Refinement and improvement of site index/quality classification and prediction.
8	Development of linkages between growth and yield information and allowable cut programs.
9	Development of implementation software for using growth and yield research.
10	Uneven-aged management research in the Great Lakes region.

The cooperative's specific objectives are thus:

1. Provide guidelines, recommendations, and limited technical assistance for data collection, especially for compatible procedure and quality control, to ensure the collection of broadly useful data.

2. Identify areas where data collection is needed and design and, where possible, install the necessary study plots or record keeping procedures (in the case of existing installations).

3. Encourage and coordinate growth and yield data collection including the establishment of priorities for research and data storage, retrieval, and access.

4. Encourage the pooling of growth and yield data, specifically by accepting such data from cooperators and cooperative members and pooling that data to make it available to cooperative members and researchers working with the cooperative.

5. Stimulate the development and localization of growth and yield prediction models to be made available to participants and cooperating organizations within the region.

ORGANIZATION

The Advisory Committee consists of representatives from each of the following groups: universities; federal forestry research organizations; local, county, state, provincial, and federal forest management agencies; industry; and other full members (as defined below). The universities and research organization roles are primarily that of research. The management agency role is to represent forest land management interests of the various landowners. In order to recognize the bilateral nature of the members, the advisory committee has two Co-chairs, each representing one of these groups. The Advisory Committee will meet at least once per year to discuss and set research priorities, review progress and approve research projects. The development of operational bylaws was an early agenda item. The bylaws were approved at the January, 1989 meeting of the cooperative. The cooperative also has at its disposal various administrative personnel to handle budgetary and accounting aspects of income, grants, and expenditures and insure that the cooperative follows established rules and procedure regarding funding and staffing. In addition to the advisory committee and its chairs, the cooperative is guided by the direction of an Administrator, whose responsibilities include overseeing the membership meetings, locating possible funding sources, and directing the work of a research specialist. This forest growth and yield research specialist will help accomplish the various objectives of the cooperative by soliciting data and cooperation, assisting in research plot establishment, collecting and pooling data and information, developing and maintaining this data base management system, and in growth model development. These developments are expected to have application across the Great Lakes region as the cooperative progresses.

FUNDING

Initiation of the cooperative is facilitated with a portion of a grant from the Legislative Commission on Minnesota Resources. The grant was for a project entitled "Future Timber Supply Scheduling Techniques." The cooperative also receives nominal support from members to facilitate its meeting, information, and communication efforts. The cooperative will also, itself and through encouragement of participating scientists, seek grants for specific projects that further the cooperative's objectives. The cooperative will continue with staff and/or financial support from the lead organizations as it develops.

The fee schedule for participation in the cooperative is as follows:

1. Full Membership entitles members to voting rights in the cooperative and, therefore, gives the opportunity to set priorities for research projects and other cooperative activities. Full members will automatically have representation on the Advisory Committee. Full members are also entitled to participate in the annual review of cooperative activities and receive all correspondence, study plans, and research results. Annual fee: public agencies, industry, and individuals - $250.

2. Contributing Membership entitles contributors to technical correspondence and research results. Contributors do not have voting rights concerning the activities of the cooperative. This membership is available to donors of field plot data records and sponsors of general or specific projects that are prohibited from paying dues by internal regulations.

The cooperative recognizes that its success will lie primarily with nonmonetary assistance from members and other cooperators, especially through their investments in field plot data collection, and the pooling of that information. Consequently, the funding support requested from members is nominal, sufficient only to cover administration and communication costs. In Minnesota, the LCMR support will furnish the first two years of project funding to cover the salary of a research specialist, travel, and data synthesis support. Beyond that the lead organizations are expected to continue to provide scientists and support staff in this general area to facilitate cooperative objectives. Staffing beyond the first two years of the cooperatives' initiation will be contingent upon scientific and technical support from member organizations and grants for specific projects obtained by the cooperative itself or cooperating scientists. The cooperative is intended to be self supporting, at least at a minimal level, due to continued interest in the subject matter.

DATA POOLING/SHARING RESPONSIBILITIES

Forest growth and yield plot data contributed to the cooperative will be maintained in confidence in computer-based storage. Upon request, members who contribute data may limit access to ownership and location information so as to maintain confidentiality of the source except for the forest type, site quality, and related stand and tree information. Contributors may also ask that their permission be obtained before data is released for specific projects. Data will be made available for studies approved by the advisory committee. The data will be maintained by the cooperative, though not necessarily at one location.

REPORTING

A primary benefit of cooperative membership will be access to the latest and best available information and models for growth and yield prediction. Cooperating scientists and their employing organizations will determine final publishing outlets. However, dues paying cooperators will be provided results in preprint format whenever possible.

PROJECTS

Specific projects undertaken for the first two years of the effort are:

1. Develop guidelines for the installation, maintenance, measurement and reporting of permanent plot records. A document, has already been written and distributed to the cooperative's members for their review (Walters and Ek, 1988). This document and refinements will serve as a basis to guide the data collection efforts of the members.

2. Identify gaps in existing permanent plot data and seek the establishment of plots to fill those gaps. During the 1988 field season, GLFGYC employees established 50 permanent growth plots at two locations in Minnesota. Both locations, the North Central Experiment Station in Grand Rapids, Minnesota, and the Cedar Creek Natural History Area near St. Paul, Minnesota, were selected because of their close proximity to weather stations. These plots should help researchers better explore the relationship between forest growth and climatic changes.

3. Develop a research oriented data storage and retrieval system for forest growth and yield plot data. The membership has already been asked to respond to a questionnaire aimed at assessing the availability of member data sets. The results of this questionnaire have been placed into a computerized catalogue system for member use. This will be updated periodically.

4. Develop simple empirical yield models for major forest types of the region with emphasis on young stands and regeneration. A case study of this problem has been completed using forest industry inventory data from Wisconsin. The results are being expanded using the U.S.F.S. Forest Survey data in Minnesota in 1989 and a project has been proposed to do the same with the Wisconsin Forest Survey data.

5. Develop refinements to the STEMS and TWIGS forest growth modelling systems to a) make them more accurate locally (e.g., develop site-specific adjustments to the simulation models) and b) facilitate their use for a wide range of user data types.

6. Develop software to facilitate the linking of these growth and yield models to forest planning systems. The GLFGYC is involved in the development of a planning system to be used by state and county land management agencies in Minnesota. This project is scheduled for completion in mid-1989.

As these projects are completed, the cooperative will shift to other work as directed by the membership. New projects are encouraged, provided they fall within the context of the GLFGYC, and are approved by the membership. Questions concerning cooperative projects should be directed to: Administrator, Great Lakes Forest Growth and Yield Cooperative, Department of Forest Resources, College of Forestry, University of Minnesota, 110 Green Hall, 1530 N. Cleveland Avenue, St. Paul, MN 55108. Phone: 612/624-3400.

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ASPEN SITE INDEX AS RELATED TO PLANT INDICATORS

D.K. Walters, J.P. Sloan, and V. Kurmis[1]

ABSTRACT.--Eighty-five fully stocked, even-aged, aspen stands representing a wide range of ages were examined. Using published site index equations, the site index of these stands was estimated. A second available indicator of site quality was the soil productivity group used by the Soil Survey. Each of these site quality indicators was related to synecological coordinates (moisture, nutrient, heat, light) of 85 stands. In this case, synecological coordinates were identified through the use of indicator plant species (synecological coordinates).

While site index is often the simplest and most straightforward method of predicting site productivity, problems can arise because of a number of factors (e.g., genetic differences, stand origin, inappropriate extrapolation of equations, and either understocking or overstocking). One possible way of avoiding some of these problems is to base estimates of site productivity on a more robust indicator. This study examines the hypothesis that synecological coordinates predicted from indicator plant species is such a robust indicator. Previous work by Sloan (1981) indicated that this was a possibility.

METHODS AND RESULTS

In this study, we examined 85 fully stocked, even-aged, aspen stands which represented a wide range of ages. The 85 stands were a subset of data collected in Carlton County, Minnesota (see Sloan, 1981 for a complete description). Table 1 provides a summary of these data.

INDICATORS OF SITE QUALITY

Several common indicators of site quality were available for these stands. Site index as estimated from published site index equations is one such indicator. Numerous published equations were examined and it was determined that the Gevorkiantz (1956) equations were most appropriate. This was based on an examination of the data and on the widespread acceptance of these equations. A second conventional indicator of site quality is the soil productivity groups used by the soil survey and developed by Lewis (1978). In this process, soil series are ranked and placed into one of seven soil productivity groups based on site index information obtained from the soil survey of Carlton County. Where possible, aspen site indices are used, otherwise interspecies correlations (Benzie 1977, Perala 1977) provide aspen site index estimates for the soil series. As part of the data collection effort in this study, various soils variables were collected, including soil series.

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Table 1.--Data for 85 aspen stands in Carlton County, Minnesota.

	Mean	Standard Deviation
Age	71.47	10.99
Site Index (Gevorkiantz)	21.94	7.16
Soil Survey Productivity	58.07	16.95
Moisture Coordinate	2.53	0.20
Nutrient Coordinate	2.56	0.19
Heat Coordinate	2.33	0.18
Light Coordinate	2.83	0.24

SYNECOLOGICAL COORDINATES

The method of synecological coordinates is used to show distribution and interrelationships of forest communities in edaphic and climatic fields. More succinctly, four fields of influence are made explicitly; moisture, nutrients, heat, and light. For this study, the work by Bakuzis (1959, 1960) was used to determine synecological coordinates for the 85 aspen stands. This work is based on the premise that moisture, nutrient, heat, and light regimes can be measured indirectly by the presence of the plants. Therefore a complete list of plant species and frequency was made for sample plots on each of the 85 stands. Each species is assigned a coordinate value for moisture, nutrients, heat, and light. The coordinate values range from a low value of 1.0 to a high value of 5.0. The values are a function of where a species most commonly occurs under prevailing competition. The values for each species existing in a stand are then averaged to provide an estimate of the four coordinate values for the stand.

ANALYSIS

Using simple correlation analysis, the site index was related to the synecological coordinates. These results are contained in Table 2.

Table 2.--Pearson correlation matrix with site index[12].

	Site Index	Age	Moisture	Nutrients	Heat	Light
Site Index	1.00					
Age	-0.54*	1.00				
Moisture	0.25*	-0.06	1.00			
Nutrients	0.28*	-0.09	0.25*	1.00		
Heat	0.10	-0.07	-0.10	0.70*	1.00	
Light	-0.16*	0.01	-0.37*	-0.57*	0.02	1.000

[1]Based on 85 aspen stands in Carlton County, Minnesota.
[2]*Indicates significance at the 90 percent level.

Similarly, the relationship between soil productivity and synecological coordinates is simply portrayed through a correlation matrix in Table 3.

After examining these matrices, it is clear that nutrient and light coordinates are highly correlated with the moisture coordinate. The highest relationship between a site quality indicator and a synecological coordinate is that between site index and nutrient status, the second highest is between site index and moisture status. The correlations are significant at the 90 percent level. A third significant relationship is between soil survey productivity index and nutrient status. Several three dimensional graphs portraying these relationships are given in Figures 1 and 2.

CONCLUSIONS

Results from this study indicate that there are statistically significant relationships between synecological coordinates and various conventional indicators of site quality. These relationships can also be detected graphically (Fig. 1 and Fig. 2). This result is useful in cases where synecological coordinates are known (as part of a habitat type system, for example) so that the land manager can obtain a numeric estimate of the site quality. Such estimates often facilitate management decisions and may be required as input to various growth and yield or planning tools. Ten ecological types were recognized and delineated on these stands. Stands in any particular ecological type are expected to be of approximately the same productivity, to have similar tree reproduction, to follow common successional trends, and to respond uniformly to treatment. Of more importance is the implication that synecological coordinates or other, similar variables may have valuable and practical role as site quality estimators in their own right. Implicit in this study is the knowledge that both site index and the soil survey productivity codes are estimates, each having a certain amount of error. So the relationship between true site quality is only an estimate. Synecological coordinates may have a much higher relationship to the true site quality than they do to the two estimates of that parameter which were used in this study.

Table 3.--Pearson correlation matrix with soil productivity[1,2].

	Soil Prod.	Age	Moisture	Nutrients	Heat	Light
Soil Prod.	1.00					
Age	0.17	1.00				
Moisture	-0.12	-0.06	1.00			
Nutrients	-0.20*	-0.09	0.25*	1.00		
Heat	-0.14	-0.07	-0.10	0.70*	1.00	
Light	0.16	0.01	-0.37*	-0.57*	0.02	1.00

[1]Based on 85 aspen stands in Carlton County, Minnesota.
[2]*Indicates significance at the 90 percent level.

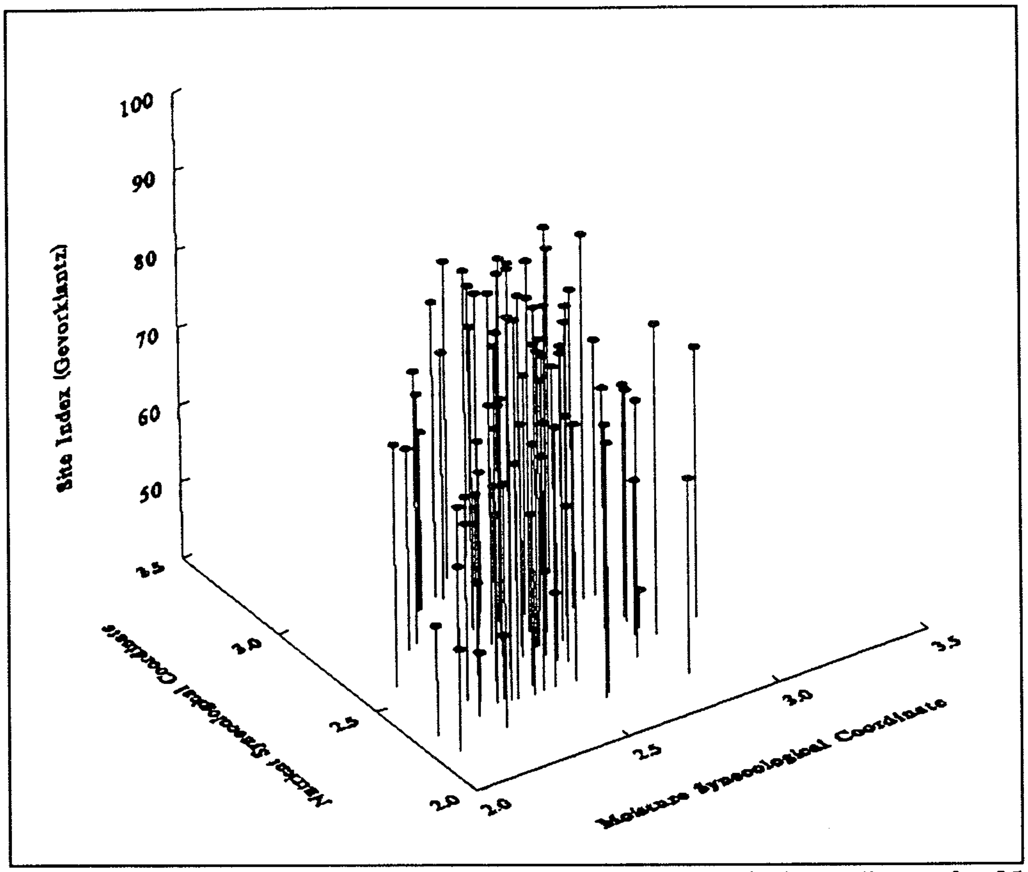

Figure 1.--Site index versus nutrient and moisture synecological coordinates for 85 natural aspen stands in Carlton County, Minnesota.

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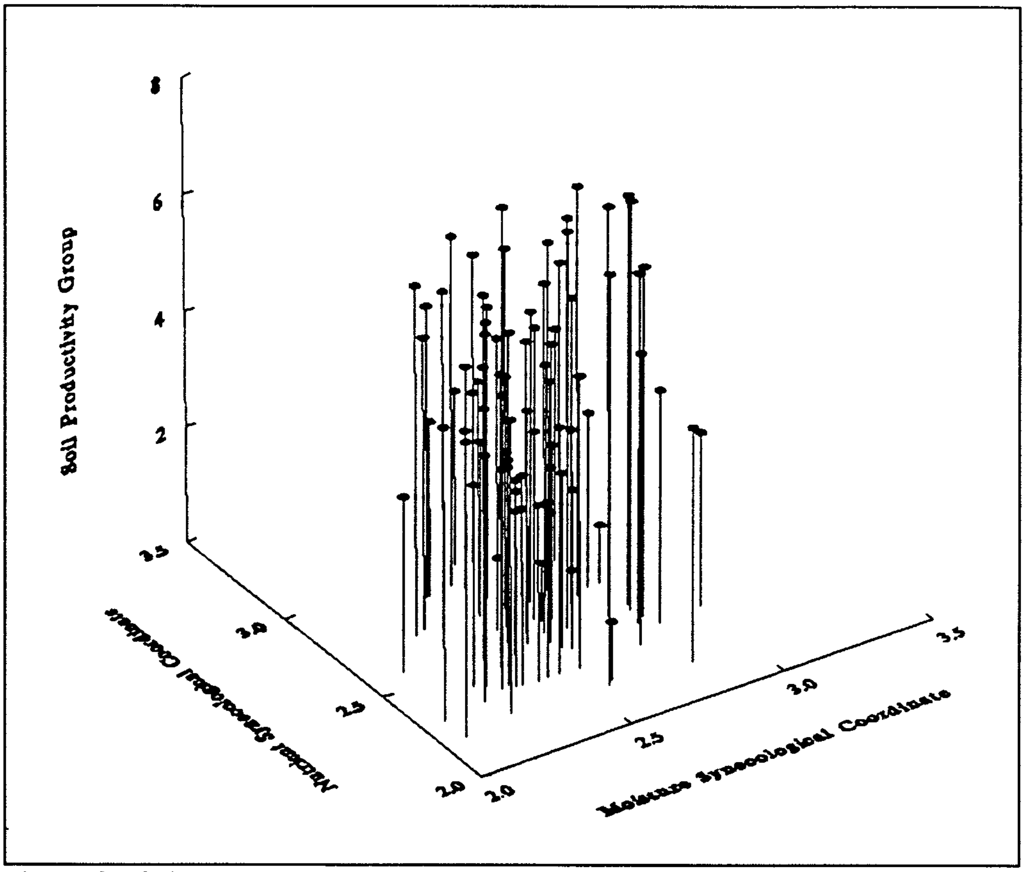

Figure 2.--Soil survey productivity index versus nutrient and moisture synecological coordinates for 85 natural aspen stands in Carlton County, Minnesota.

OPPORTUNITIES FOR ASPEN UTILIZATION IN COLORADO AND THE ROCKIES

E.M. Wengert and B.W. Karaim[1]

ABSTRACT.--This is a paper presented at the 1976 Symposium entitled "Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains" held in Fort Collins, Colorado. The volume of aspen resource in Colorado and the Rocky Mountains is significant yet it is still underutilized. This species, often referred to as a weed tree, will become more important in the future particularly for the panelboard and pulp industries. Increased forest management activity of the aspen resource will facilitate increased utilization.

INTRODUCTION

Aspen (Populus tremuloides Michx.)[2], also commonly called "popple," "poplar,"[3] "quaking aspen," and "quaky," is the most widespread species in North America, stretching from Mexico to the Arctic Ocean, Maine to California. The range is controlled by adequate moisture levels and cool summer temperatures.

Important commercial concentrations of aspen exist in the Northeastern United States, the Great Lakes area, central portions of Canada, and in the Central Rockies. In the Central Rocky Mountains, commercial aspen is generally confined to elevations between 7,000 and 11,000 feet. Although aspen is widely distributed in the Rockies, important commercial saw-timber concentrations are limited to North Central and Southwestern Colorado, Northern New Mexico, and South Central Utah.

Aspen is extremely important in the overall resource/land use picture in the Rocky Mountains. It is extremely beneficial for watershed improvement, soil building, and wildlife forage, as well as for recreational uses and scenic beauty. As a generalization these preceeding benefits are the management objectives for the species. Unlike the Lake States, then, the aspen resource in the Rocky Mountains is not managed directly for the fiber that it can potentially provide for wood products. And yet, aspen in Colorado has an annual volume increment of 120 board feet per acre (Miller and Choate 1964), well above ponderosa pine, but below Douglas-fir. Further, the Rocky Mountains have more sawtimber volume (DBH 11-inches and greater) than the Lake States (Table 1). Colorado has 17 percent more sawtimber volume than Michigan, 32 percent more than Minnesota, and 49 percent more than Wisconsin.

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[2]In some geographic areas "aspen" includes P. grandidentata Michx., and P. balsamifera L. (commonly called big-tooth aspen and balsam poplar respectively). In the Rockies, the only significant aspen species is P. tremuloides Michx.

[3]Poplar in the eastern U.S. lumber trade can refer to yellow-poplar (Liriodendron tulipifera L.).

Table 1.--Net volume of aspen growing stock and sawtimber on commercial forest land, 1970.

	-------GROWING STOCK--------		--------SAWTIMBER--------	
	Aspen Volume (Million cu. ft.)	Aspen Volume Compared With Total Growing Stock Volume (%)	Aspen Volume[1] (Million bd.ft.)	Aspen Volume Compared With Total Sawtimber Volume[2] (%)
		Rocky Mountains		
Colorado	1,807.4	15	3,142.4	8
Utah	1,038.5	22	1,574.4	7
New Mexico	600.9	9	1,475.3	11
Arizona	226.1	5	678.7	3
Wyoming	170.3	4	199.4	2
Idaho	68.6	0	117.0	1
Montana	51.4	0	74.1	0
Nevada	12.2	5	21.8	
TOTAL	3,975.4		7,283.1	
		Lake States		
Wisconsin	2,159.5	20	2,109.3	11
Michigan	2,257.1	15	2,684.0	9
Minnesota	3,018.2	31	2,387.9	18
	7,434.8		7,181.2	

[1]1/4" INT rule.
[2]Includes softwoods 11" DBH and greater.

Sources:

Green and Setzer (1974) for RM data
Chase et al. (1970) for Michigan data
Spencer and Thorne (1972) for Wisconsin
Spencer (1968) for Minnesota

In terms of acreages, the Rocky Mountain States have 4.1 million acres of aspen-type, commercial forest land (CFL) (Green and Setzer 1974) as shown in Table 2.

This is only 31 percent of the aspen CFL in the Lake States (Minnesota, Wisconsin, and Michigan).

However, aspen-type occupies a significant part of the commercial forest land in the Rocky Mountains. In Colorado, aspen-type acreage is 25 percent of the total commercial forest land; in Utah, 31 percent (occupying more land than any other forest type); and in New Mexico, 6 percent. Sixty-five percent of this aspen-type acreage is public land.

Table 2.--Aspen-type commerical forest land in Rocky Mountain States.

State	Aspen-type Acreage (Acres)	Commercial Forest Land in Aspen-type (%)
Colorado	2,288,900	25
Utah	1,105,300	31
New Mexico	346,100	6
Wyoming	187,900	6
Arizona	89,900	2
Idaho	60,200	0
Montana	44,700	0
Nevada	6,500	5
TOTAL	4,129,500	

In recent years the importance of managing aspen and maintaining the species as an important component of our Rocky Mountain forest has been recognized.

Indeed, many of the benefits obtained from the species cannot be achieved without proper management.

In the past an important "natural" aspen management tool was wildfire. Young aspen, arising from root sprouts, would quickly re-forest a burned conifer area. As these aspen sites matured, they frequently would naturally revert back to conifers in 100 to 200 years. However, with the control of wildfire (and with the present cutting and logging practices in the conifers that do not open up large areas) conditions are often unfavorable for large scale aspen regeneration (Schier 1975). Yet, as stated above, it is important to keep the aspen forest as part of the total Rocky Mountain forest in widespread locations. The management tool that is available to do this is aspen wood utilization. By logging aspen in small, cleared areas, the aspen will regenerate and the type can be maintained where and when desired (Jones 1975).

With this rosy picture, it might seem as though the resource is waiting to be tapped. Yet annual usage is below 10 million feet. Frequently, the lack of markets or availability of better species (i.e., conifers) is blamed for this lack of utilization. Indeed this may be part of the problem, but the resource itself also causes some difficulty:

1. Two-thirds of the aspen sawtimber is between 11 and 15 inches.

2. Decay becomes significant on poor sites well before commercial size is attained and on good sites shortly after sawtimber size is reached.

3. Aspen is generally scattered in large and small groves interspersed among the conifers increasing procurement and handling costs.

4. Other uses or demands on the resource preclude harvesting.

5. The form of the tree increases harvesting, transportation, and milling costs.

6. Snowfall limits accessibility to three to six months per year.

The impact of these items should not be underestimated. Some of these will be discussed in subsequent papers in more detail.

The regional and national demands for fiber also may affect the resource and its utilization... and vice versa. The U.S. Forest Service's analysis, " The Outlook for Timber in the United States," indicates increases in per capita consumption of wood (both in solid forms such as lumber and in reconstituted forms such as paper) as well as increases in population. The demand in 1970 was 12.7 billion cubic feet; the projection for 2000 is 23 billion. It is projected that roundwood hardwood removals in the Rocky Mountains will increase from 3 million cubic feet in 1970 to 76 million cubic feet by 2000. Of course, these are only projections but they do indicate the increasing utilization pressure on the resource. We believe aspen will become a more acceptable species because:

1. The industry is cutting and processing more small diameter timber.

2. Fiber or particleboard mills will become established in the region.

3. Landowners will become more aware of the management needs of the species.

In summary we have a significant aspen resource in the Rocky Mountains. Over the next few decades utilization will become an important management tool for maintaining the resource and its benefits.

MARKET OPPORTUNITIES

This is a summary of some of the information presented in a report by this author entitled, "Guidelines for Utilization and Marketing Rocky Mountain Aspen" published by the USDA Forest Service Rocky Mountain Station.

The potential for any large scale use of Rocky Mountain aspen lumber is limited by (1) high processing costs, (2) market limitations imposed by grading rules, and (3) high transportation costs to most market areas. As these problems are solved, the outlook should improve. Small market niches do exist at present and can be expanded; these uses include wire spools, cash-and-carry utility lumber, specialized containers, decorative paneling and mine timbers.

Because of the abundance of conifers and conifer residues, prospects for utilization of aspen for pulp, particleboard, or fiberboard in the Rocky Mountains are not immediate. At present, there are no fiberboard or particleboard plants within the area and only one pulp mill in the Southwest--inaccessible to most of the aspen resource.

Because of aspen's small size and high incidence of defect in the core, conventional veneer production has very low potential. There are no plywood mills in the area, although there is one match splint factory that produces veneer for that purpose.

Fuel demand in the Rocky Mountains is quite low as there are few industrial users when compared with other areas in the U.S.A. Hence, fuelwood has a low potential except within the industry and for fireplace wood.

All indications are that there is good demand for wood residues for animal and poultry bedding. However, most of this demand is east of the Continental Divide while the aspen is west.

The use of aspen for excelsior in the West has been continuing for many years and probably has utilized more aspen sawtimber than any other use. The excelsior industry has been subject to many oscillations in demand. However, with shortages in plastics, it might be anticipated that demand for excelsior will increase.

There are certainly other market niches for aspen such as paneling, shingles, stakes, tongue depressors, novelty items, wood flour, etc. that will continue to use small amounts of raw material and manufacturing residues. These uses should be developed further.

THE COLORADO PROGRAM

1. First one had to develop a Prospectus on the problem. This included a six week period of visits with industry, Forest Service and other forest management people throughout the Rocky Mountain region. Also included was a two week visit with industry people in the Lake States. A written document discussed these visits and the forest management requirements.

2. Next, a problem analysis was developed that outlined the major barriers to utilization and marketing. Again, the effort was directed at the requirements for forest management rather than the increased need for wood fiber, per se. The major barriers to utilization and marketing were the lack of tree and log grades, the lack of market information, the lack of yield information for sawn products and a general poor understanding of the species' properties by both forest managers and the industry.

3. Study plans were then developed to address the major barriers. Appropriate research was then conducted. Tree grades and log yields were developed from information gained through these studies. The extent of decay was analyzed, with the impact of decay, tree age and site quality factored into predictive equations that estimated the amount of cull (board foot basis). Marketing information was prepared, including processing requirements, processing costs, and market size and location.

4. Reports were written summarizing the information collected in both the research studies and in the prospectus and problem analyses.

5. A seminar for forest managers and industry was held to convey the information that had been assembled.

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